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Six-Unit Four-Ball Wear Machine (See Page 40)

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Editorial

The end of the war should cause all of us to analyze certain of its effects.

Research, in many ways, has made enormous progress during the war years. In fact, it has been estimated that in the five-year period 1940-1945, as much progress has been made as would normally have occurred under peace conditions during a quarter of a century or more. Evidence of this is before us in such things as radar and electronic developments, new discoveries in the field of chemistry and medicine, new materials, fuels and lubricants, and finally success in reaching the threshold of controlled atomic energy.

Some statistics on research might be of interest. In the year 1938, which in some ways represents the last normal year, research of all types in this country totaled $263,722,000 with $49,382,000 appropriated or used in Government Research Agencies. In contrast to this, during the year 1944, Government appropriations for research alone totaled $719,813,000 with the total for industrial and other forms of research not yet available. The federal cost figure for research alone thus increased some fifteen fold.

In contrast to this picture we must examine the cost of war where, in addition to the toll in life, in suffering and material damage, research and progress have suffered as well. A pressing problem now faces research and industry. The young men who, in normal times, would have gone into graduate study and into the development end of industry have not done so but, by virtue of necessity, have been drawn into military service. The numbers which have been taken away represent almost the whole output of scientific, trained personnel at higher levels. From the period 1941 to 1945 the number of men leaving the Universities with advanced degrees approach the vanishing point. Many Universities discontinued graduate instruction completely, both because there were no students and because the faculties of trained scientists were so vitally needed on War and Industrial Research problems.

Doctor Vannevar Bush, Director of the Office of Scientific Research and Development, whose group of research workers contributed so materially to winning the war, following a request made by President Roosevelt, prepared a report which has now been released under the title "Science, the Endless Frontier." In this, the whole problem of the dearth of scientists and engineers trained on a higher level is discussed and a statement is made that the deficit of scholars with advanced training created through the period 1941 to 1945 is in excess of 3,000. This number seems small when first considered, but it must be realized that the deficit does not stop at that period because adequate training of a high-grade research worker takes a minimum of six years of collegiate background so that this deficit will increase in the period 1945 to 1950 to a point where by 1950 it may be in excess of 10,000 men. This imposes a serious problem on research laboratories, industry and the Universities, but it is not a hopeless one nor one which should interfere with each one of us bending every effort toward peacetime recovery.

The G I Bill of Rights will unquestionably return men to studies at higher levels. In addition, Doctor Bush's Committee proposes that Congress should appropriate funds whereby, under a scholarship system, a larger number of students can be trained in engineering and science with their expenses partly paid by the Government. This move seems very wise, and it is hoped that something of this nature will be done. Universities will be crowded and over-loaded but will certainly work to their utmost in an effort to make up the deficit which has accrued.

Success in peace must be our new objective and we know that the lubrication group will continue its efforts in staying in the front ranks of progress.

B. H. JENNINGS.

The Study of Lubrication Using The Four-Ball-Type Machine*

By R. G. LARSEN

Shell Development Company, Emeryville, California.

LUBRICATION is such a complex phenomenon and operates under so wide a variety of conditions that no single machine has been found suitable for its complete study. Two types of lubrication are recognized, namely:

(1) Hydrodynamic, in which two solid surfaces, moving relative to each other, are separated by a continuous viscous load-carrying film;

(2) Nonhydrodynamic, in which the lubricating film is not continuous and the metal surfaces actually come in contact.

In the first case, viscosity of the lubricant determines its applicability to a given bearing and will not be discussed here since viscosity is a simple and well-defined property which can be measured under precise laboratory conditions. On the other hand, characteristics of the lubricant which are important under nonhydrodynamic conditions have not yet been completely defined and many widely different types of apparatus and experimental techniques have been devised for their investigation. This report constitutes a review of several machines employing the four-ball-type bearing which have been used successfully for studying wear, friction, and seizure, the most important aspects of nonhydrodynamic lubrication.

The Four-Ball Principle

Four balls made of the metal under investigation (usually steel) are arranged in the form of an equilateral tetrahedron as illustrated in Figure 1. The basic elements are three lower balls held immovably in a clamp to form a cradle in which a fourth or upper ball is caused to rotate about a vertical axis under prescribed conditions of load and speed. The contacting surfaces on the four-ball-type of apparatus are geometrically well-defined, thus providing obvious advantages in the study of wear and friction phenomena.

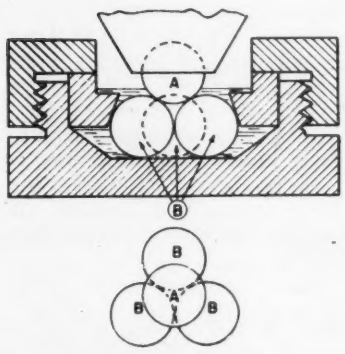


FIGURE 1
Four Ball Bearing

From the geometry of the system, the load on each of the lower balls can be calculated by the equation:

$$F_1 = 0.408\ F,$$

where: F_1 is the force normal to surface of contact on the lower balls exerted by the total applied load F.

The actual pressure existing over the contact area depends upon the area as well as the applied vertical load. This area, before wear has occurred, depends only upon the elastic properties of the contacting surfaces which will be flattened to some extent by deformation under pressure. The diameter of the contact area between two spheres can be calculated by the Hertz equation which, for elastic hard-steel balls, is reduced to:

$$d_H = 0.0873 \sqrt[3]{P},$$

where: d is the diameter of circle of contact in millimeters. P is the load in kilograms on the upper ball.

As soon as rubbing between the contacting surfaces begins, the circle of contact is marred or the metal is actually cut away. If wear occurs, the diameter of this scar will be larger than the original contact circle and the pressures are reduced. The applied load and area of contact (scar diameter) being known, it is easy to calculate the pressure existing between the rubbing surfaces. In the following discussion general principles involved in the measurement of wear and friction will first be reviewed, after which the different types of apparatus involving the four-ball principle will be described.

The Measurement of Wear and Seizure

G. D. Boerlage[1] was the first to use the four-ball bearing in an apparatus for the study of lubrication. His machine was designed to test the so-called extreme-pressure lubricants and was built to operate under very severe conditions (high loads). Since that time, several modifications have been devised for operation under lower loads and there are now machines available that altogether cover a load range of 0.1 to 1000 kg (pressures of 5,000 to 400,000 psi at the rubbing surfaces) and wide range of speeds. It is important that a wide load range be investigated, for the relative behavior of lubricants under high loads may be quite different from that under lower loads. In Figure 2 examples of lubricant behavior at various loads are given for a mineral oil, a low-wear oil, and an extreme pressure lubricant. The left-hand set of curves presents the results of two-hour tests run at low loads. At the lowest loads it is seen that, provided the oil gives little wear and thus maintains scar diameter at a low value, pressure is higher when load is higher. However, a load is finally reached where breakdown

*Presented Before the Cleveland Chapter, A.S.L.E., May 7, 1945.

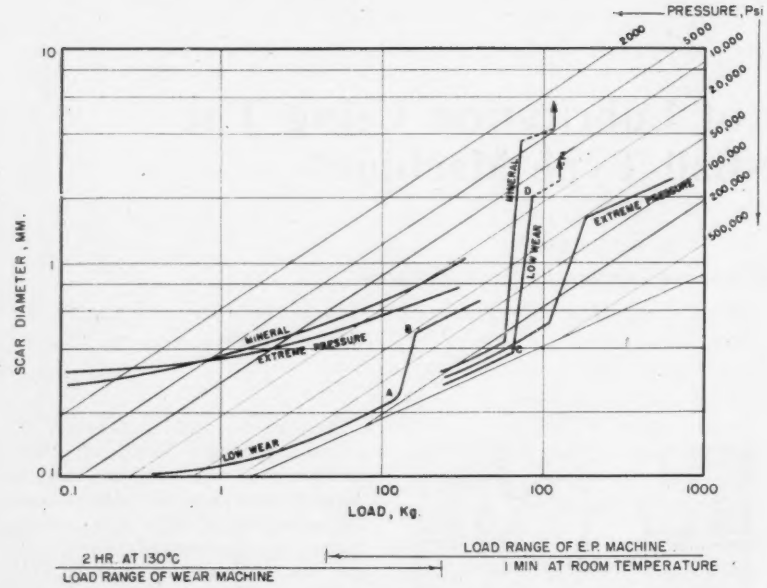


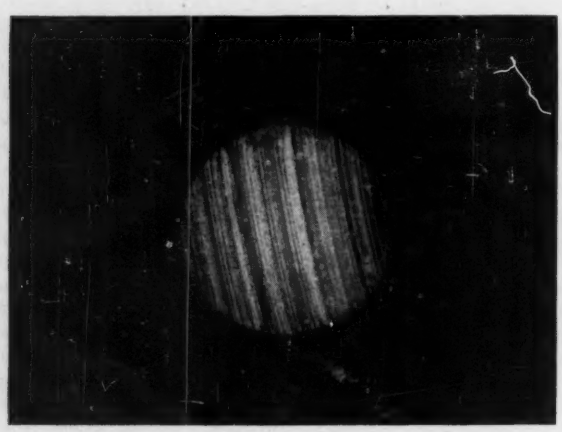
FIGURE 2

Idealized Wear Versus Load Curves for Various Four-Ball Machines With Different Types of Lubricants.

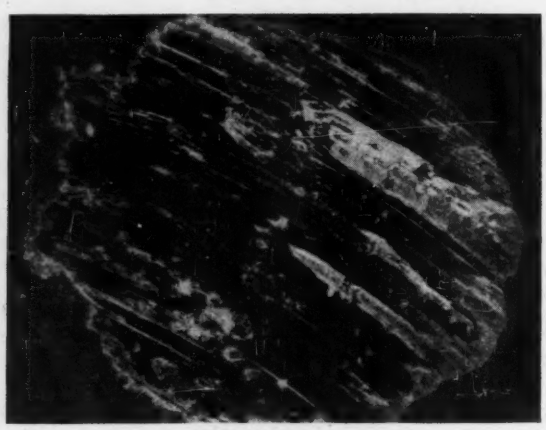
occurs, as at point A on the curve for the low-wear oil, because of the loss of the wear-preventive film. Since it occurs under relatively low applied loads, the amount of energy involved is small and only a small part of the surface of the ball is affected. The outcome of this type of breakdown is not serious, the only detectable effect being an abrupt rise of measured scar diameters. It is possible that some metal-to-metal contact and occasional seizure occurs, but only a minute fraction of the rubbing surfaces is involved and seizure may be regarded as submicroscopic. At point B and beyond, the average pressure is lowered to the point where no further disturbance of the film occurs. Conditions are then stable and scar diameters are proportional to the load during the regular two-hour runs.

In studying the effects of higher loads a series of experiments of only one-minute duration are run, as represented by the set of curves on the right-hand side of Figure 2. The shorter time is chosen because, at the high loads, seizure may occur shortly after the start of the test, which leads to drastic breakdown of the rubbing surfaces, vibration, and erratic operation of the machine. In the load range from 20 to about 40 kg, scar diameters are smaller than those obtained during the two-hour tests and are proportional to the load. At higher loads, breakdown occurs (point C) but, unlike the breakdown at point A, temperatures and pressures are so high that shear strength of the metal is exceeded with resulting plastic flow and seizure of a severe type. The effects are evidenced in a number of ways. First, conditions at the wearing surfaces are changed as shown by the photomicrographs in Figure 3. Whereas the wear scar is circular and smooth without evidence of metal transfer or smearing below the point of seizure (Figure 3A), there is a large increase in size and evidence of plastic flow of metal above this load (Figure 3B). Also, seizure is accompanied by a large increase in friction, as will be discussed later. At point D there is stabilization and, for a while, further increase in load can be tolerated. However, at point E, intense seizure or actual welding occurs and the friction rises to a value equal to the shear strength of the metal; the top ball then slips in the chuck and the machine must be shut off immediately. In the lower half of Figure 4 is a photograph of a set of welded balls.

By comparison with the curve for the low-wear oil (Figure 2), it is seen that mineral oil, because it permits more wear to occur, does not reach a breakdown pressure until the region of seizure and therefore the submicroscopic type of breakdown is not observed. As with the low-wear



A



B

FIGURE 3

Photomicrograph of Wear Scar on Lower Ball at Loads Below the Point of Seizure. Two-Hour Test at 15kg. Load. Magnification=40×.

Photomicrograph of Wear Scar After Seizure has Occurred —1 Minute Test at 50kg. Load. Magnification=40×.

oil, it offers little protection against seizure and welding.

The extreme-pressure oil may give even higher wear at low loads than does the mineral oil. However, seizure is usually delayed and hence breakdown does not occur unless higher loads are used. Furthermore, welding is minimized and does not occur until the pressure is increased considerably beyond the breakdown point. The upper set of balls in Figure 4 was run with an extreme-pressure lubricant under the same conditions that led to welding with an undoped mineral oil. Wear was high but not excessive and no transfer of metal or plastic flow occurred.

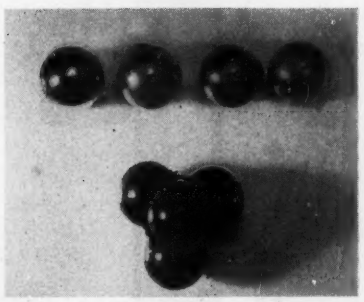


FIGURE 4
Seized and Unseized Balls Used in the Four-Ball Extreme Pressure Lubricant Tester.

These examples demonstrate that, with two machines covering a wide range of loads, considerable information can be obtained on the characteristics of a lubricant. It is also evident that, in selecting a lubricant for some particular service, the essential problem should be recognized; a low-wear oil may be required in one case, as in lubrication of piston rings of an engine, while a lubricant that is capable of preventing welding although permitting high wear should be specified for lubrication of hypoid gears.

Measurement of Friction

Friction is generally measured by determining the torque on the lower-ball holder. However, in one modification, the Four-Ball Top, friction is determined by the rate of deceleration of the upper ball and loading assembly which rotates freely after an initial impulse. As in the case of wear, the type of friction which occurs is governed by the experimental conditions. At the point of seizure and again at welding, friction increases abruptly. Below these loads friction remains fairly constant and is a useful indication of the behavior of oils in some lubrication processes. In a recently published article[2] it was shown that ultimate reduction in friction and in wear cannot be attained simultaneously; in fact, under some conditions the two phenomena appear to be competitive. With the machines described, emphasis can be placed on wear, friction, or seizure, for any desired application.

Review

Advantages of the four-ball principle for a study of lubrication phenomena are briefly listed below:

1) The test pieces (½-inch steel SKF balls) are inexpensive, commercially available, and reproducible in quality.

2) The system is geometrically well-defined.

3) Wear can be measured optically long before measurable weight losses occur.

4) Coefficient of friction can be directly determined by the torque on the lower-ball holder.

5) Very little oil is required (about 10 cc. per test).

6) The test temperature can be easily controlled.

7) The machine can be used over a wide range of loads, speeds, and temperatures.

A description of various Four-Ball Machines and the uses for which they are intended follows.

The Four-Ball Extreme-Pressure Lubricant Testing Apparatus

In his original apparatus for testing extreme-pressure lubricants, Boerlage[1] intended that the machine should evaluate:

(1) protection against seizure, i.e., increase of the load at which seizure occurs, since this is the principal function of an E.P. lubricant;

(2) seizure intensity, to differentiate further between lubricants giving equal protection against seizure;

(3) normal wear and friction, since most gears operate in the region of moderate loads where no seizure occurs.

The Four-Ball E.P. Machine indicates all these properties of a lubricant. For rating E.P. lubricants at least four methods have been proposed which are either slight variations in testing procedure or interpretation of the data.

Description of the Machine

An assembly drawing of the original machine (Figure 5) and a photograph (Figure 6) show the various parts of the apparatus in some detail. For further particulars the reader is referred to the original articles and to the instruction manual of the machine manufactured by Precision Scientific Co., Chicago, Illinois. Briefly, an upward thrust given by the loading lever, acting on the ball holder, presses the three fixed lower balls against the upper rotating ball with a vertical force of 10 to 800 kg which results in a mean pressure on the rubbing surfaces of 15,000 to 60,000 kg/cm^2 (100 to 400 tons per sq. in.) before wear. At 1500 rpm the sliding speed between the balls is about 1.9 fps.

The ball holder is supported by a thrust ball bearing which permits horizontal displacement, insuring automatic centering of the underlying balls and making possible measurement of the frictional torque exerted on the lower balls. This is done by connecting the arm of the ball holder to a friction recorder consisting of a spring-restrained stylus moving across a revolving drum. No provision is made for temperature control.

The Friction Diagram

At relatively low loads (below about 40 kg) there is no detectable seizure and, after an initial high-friction peak which occurs when the motor is turned on, friction will remain constant over a considerable period of time. At high loads seizure may occur within a short time and friction curves of the type shown in Figure 7 are obtained. The time lapse before seizure occurs is shorter at higher loads, other factors such as temperature being equal. Furthermore, as can be seen from the figure, there is a recovery from seizure and friction may be restored to approximately the old value, generally remaining at this low value until intense seizure or welding occurs. The reason for recovery following the first seizure is not entirely clear, but it has been suggested that it is a result of the increase in temperature accompanying seizure leading to an activation of the chemical constituents of the oil; these then react with the hot surface and corrode away high spots, causing a smoothing of the surface which became very rough when seizure occurred. Also, of course, the pressure drops because of increased area of contact which permits lubrication to be established

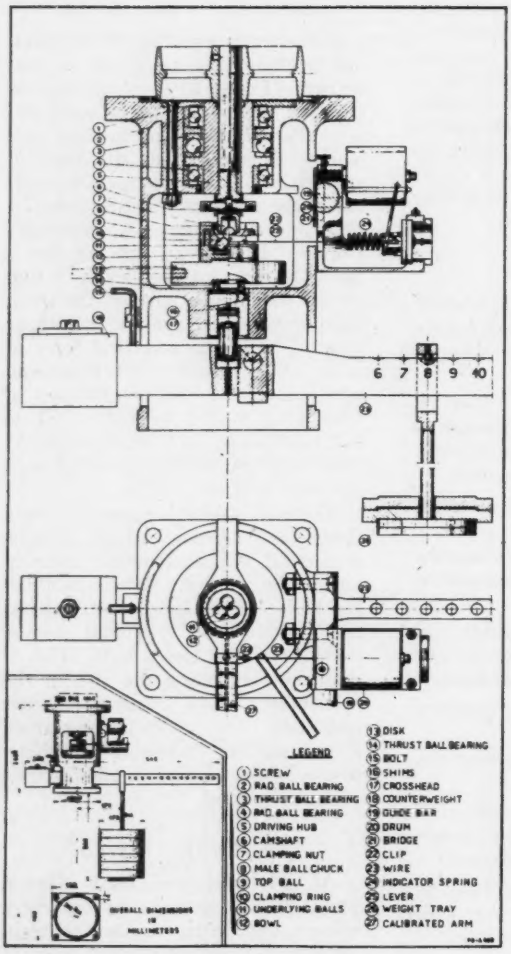


FIGURE 5

The Boerlage Four-Ball Extreme-Pressure Lubricant Testing Machine. (Assembly Drawing.)

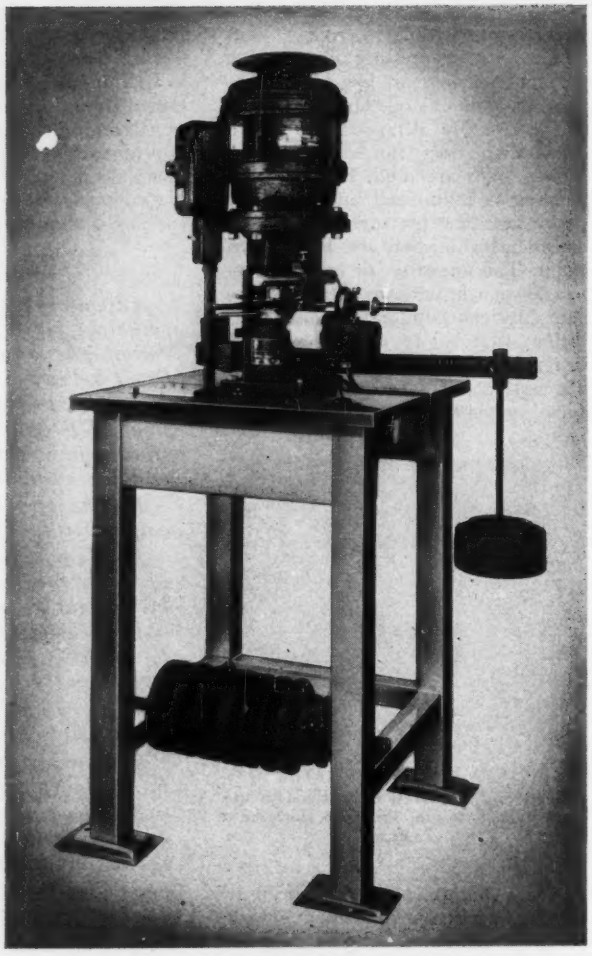


FIGURE 6

The Shell Four-Ball Extreme-Pressure Lubricant Tester.

again. The difference between the wearing surfaces before and after seizure occurs is shown in Figure 3.

Friction curves have been interpreted in terms of gear operation by D. Clayton[3], who places considerable emphasis on the magnitude of friction at the seizure point as well as the time for recovery. In general, it may be assumed that the qualities of an oil which result in low maximum friction at seizure and quick recovery from seizure are important for running-in as well as for preventing damage should momentary breakdown occur. Seizure of this type is probably not detectable in actual gears, since it is of short duration and does not lead to immediate failure. When intense seizure or actual welding occurs, the friction rises to a value equal to the shear strength of the metal.

The Wear-Load Diagram

The friction-time diagram discussed above does not indicate the amount of wear which occurs or the intensity of seizure, although an indirect indication of the latter is given by the maximum friction accompanying seizure. Pertinent information is obtained from the wear-load curves (typical examples of which are shown in Figure 8) representing results obtained by operation for one minute at the designated pressures. The relatively flat portion of the curves following the breakdown corresponds to the recovery-from-seizure region of Figure 7. Finally, welding occurs as designated by the arrow. Seizure intensity may be related to seizure-wear, that is, the increase in scar diameter with seizure (cf. Figure 8). It is thus seen that the extreme-pressure oil greatly reduces intensity of seizure and also usually increases the breakdown or seizure load. It gives lower wear at higher loads but greater wear at low loads than does the mineral oil.

The discussion of the type of data afforded by the Four-Ball Extreme-Pressure Lubricant Testing Apparatus has by no means been complete, but consideration has been given to friction, wear, and breakdown under various conditions of operation; from these data it is possible to form a fairly adequate concept of the behavior of a series of lubricants. A number of special tests which emphasize certain aspects and make special interpretations of the results are given below. In general, one criticism of these methods may be made, namely, that they all attempt to indicate by a single figure

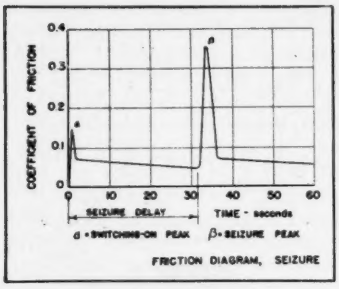


FIGURE 7
Friction—Time Diagram. Four-Ball Extreme-Pressure Lubricant Tester.

or expression behavior which is too complex to be correctly expressed in so simple a manner.

One-Minute Welding Load

If the load on the machine is high, the heat produced at the highly loaded surfaces is sufficient to cause rapid and complete welding of the four balls. This principle is used in the one-minute welding load test wherein the lowest load at which welding will occur in one minute is determined. Although not considered a reliable quantitative indication of the service performance of a lubricant, the test serves admirably as a demonstration of the action of an E. P. oil under one specific set of conditions.

Temperature-Wear Factor

A method of expressing test results obtained with the Four-Ball Machine was developed by Kemmerer and Garton[4], based on the observation of Blok[5] that there is a characteristic "temperature at seizure" for each combination of lubricant and rubbing surfaces. In fact, Blok states that the main factor controlling seizure is the local temperature and not the specific pressure of contact of the surfaces. He therefore prefers the term "Extreme Conditions Lubricants" rather than "Extreme Pressure Lubricants." It is reasoned that there is a delay in seizure on the four-ball machine (Figure 7) because a definite time is required for surface temperature to become high enough so that melting, seizure, and removal of pieces of metal occurs. Consequently, if the bulk oil temperature at the beginning of the test is high, less time will be required for seizure to occur. Or, stated differently, seizure will be reached at a lower load if oil temperature is high. Confirmatory evidence was obtained in the four-ball machine by Kemmerer and Garton who conducted regular one-minute tests at bulk oil temperatures of 80 F and 200 F, as shown in Figure 9.

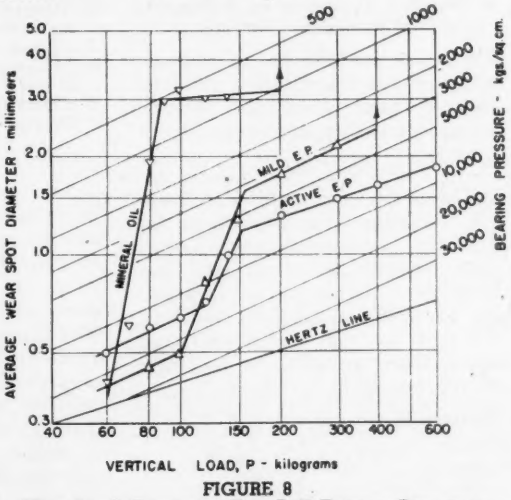


FIGURE 8
Wear-Load Curves on Four-Ball Extreme-Pressure Lubricant Tester.

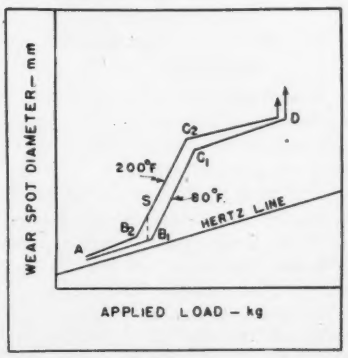


FIGURE 9
Wear-Load Curves Obtained with the Four-Ball Extreme-Pressure Lubricant Tester at Two Temperatures.

At loads below which seizure occurs there is practically no difference between results obtained at the two temperatures. However, since seizure will occur at a lower load at 200 F than at 80 F, a point of maximum spread (e.g., S) will be obtained. In the high-load range there is again little difference, although welding will generally occur at a lower load at high temperature. The magnitude of the difference between the scar diameters at point S depends upon the efficacy of the extreme-pressure agent in the lubricant.

From these data a "temperature-wear" factor was derived by means of the expression:

$$K = \frac{W_{T_1} - W_{T_2}}{T_1 - T_2} \times 1000$$

where: W is the wear spot diameter in millimeters,
T is the bulk oil temperature in degrees Centigrade, and
K is taken at the positive maximum difference between the wear scar diameters at T_1 and T_2.

According to this equation, K appears to be a temperature coefficient of wear so that T_1 and T_2 can be chosen at will. This is not the case, however, since the temperatures must be chosen so that seizure occurs in one case and not in the other; in other words, they must be above and below a critical value. The data of Figure 10 obtained on a mineral oil indicate that the chosen temperatures of 80 F and 200 F give reasonable assurance that the critical seizure temperature is being bridged for this oil. The following simplified equation for K can now be used,

$$K = (W_{200\,F} - W_{80\,F})\ 15$$

Typical data determined on a number of lubricants by this method are tabulated below. The gear ratings were obtained both on road tests and on the chassis dynamometer, a low rating denoting the best lubricant.

TABLE I
Comparison Between Four-Ball and Gear Ratings of Seven Lubricants

Lubricant	Shock Load Rating	Average Gear Rating	Temperature-Wear Factor Rating	2½-Sec. Seizure Load Rating
1	Pass	3	2	1
2	Fail	6	5	5
3	Fail	5	6	3
4	Pass	2	3	3
5	Fail	4	4	5
6	Pass	1	1	2
7	Fail	7	7	7

It is seen that, on the whole, correlation with gear tests is satfactory.

Seizure-Delay Method

The importance of temperature in determining whether seizure occurs has already been discussed. Since the seizure-delay method has been described in detail by Blok[5], it will be reviewed here but briefly. If the

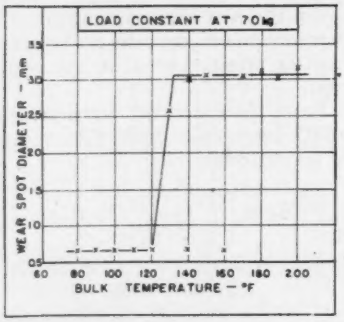


FIGURE 10
Effect of Bulk Temperature on Seizure in the Four-Ball Extreme-Pressure Lubricant Tester.

oil and steel balls are initially at ambient temperature, there will be a definite time lag before the surfaces become sufficiently hot to permit seizure, as shown in Figure 7. On the basis of a theoretical analysis of the temperature at the surface, which is related to friction, load, and time, curves of the type shown in Figure 11 were obtained. The final temperature at the contacting surfaces will depend upon the ambient temperature, t_0, plus the temperature rise, t_1 which would occur if the parts into which the heat penetrates were of infinite heat capacity, and t_2, which is a correction to t_1 and represents the increase in temperature of the ball as a whole. Whereas t_1 is an extremely rapid temperature rise localized at or near the contact surface and responding very quickly to external influences, t_2 is a gradual and fairly even increase. Thus, at each load, a definite time elapses before incipient seizure occurs, viz., the so-called seizure delay, and curves of the type in Figure 12 are obtained which show the relationship between time to seizure and load. By further mathematical development Blok concluded that the most reliable indication of protection against seizure in the Four-Ball Machine is at the load which causes seizure shortly after the test is started. The 2½-second seizure period was adopted as the shortest practical time that can be conveniently determined. From Figure 12, it is seen that this load varies from about 60 kg with undoped oil to 170 kg for an oil containing E. P. additives.

Blok found rather satisfactory correlation between the 2½-second seizure load and the lowest load on a Chevrolet hypoid gear used in a four-square gear testing rig. In general, it appeared that the seizure load must be higher than 140 to

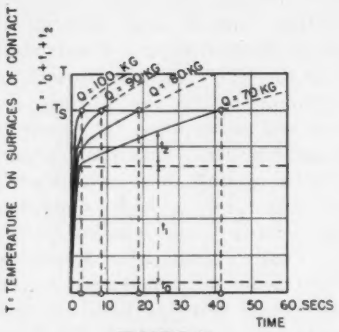


FIGURE 11
Temperature T on Surfaces of Contact of Four-Ball Apparatus as a Function of Load Q and Time.

150 kg for the lubricant to lubricate a hypoid gear successfully. Also the data of Table I indicates general agreement with gear ratings.

Pressure-Wear Index.

This is the latest method proposed for evaluating data obtained on the Four-Ball Extreme-Pressure Lubricant Testing Apparatus and has been used in recent specifications for oils and greases. It is based on the wear or scar diameter-load curve, more specially, on the slope of the line C D in Figure 2.

Pressure-Wear Index,

$$(PWI) = \frac{L_2 - L_1}{d_2^2 - d_1^2}$$

where: L_2=load at upper point D,
L_1=load at lower point C,
d_2=wear spot diameter corresponding to L_2,
d_1=wear spot diameter corresponding to L_1.

It is considered that the P.W.I. is a measure of pressure supported per unit area of the wear spot in the region of delayed seizure.

The load at C and D cannot be found by individual determinations since, in these critical regions, considerable variation in results may occur. Accordingly these are best determined graphically from data obtained on the B C and D E branches of the curve. More recently it has been proposed that, instead of graphical determination, L_1 be defined as the heaviest load in the B C region which gives circular wear scars, and L_2 as the lightest load in the D E region which consistently gives large wear scars (see Figure 3). The load, L_2, usually corresponds to point D, while L_1 is less than the graphical C. The general range covered by the pressure-wear index is as follows:

Mineral Oil	0—4 or 5
Mild E. P.	5—15
Active E. P.	15—100

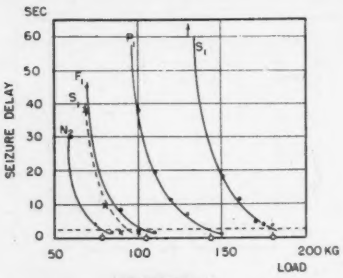


FIGURE 12
Seizure Delay Curves on Four-Ball Apparatus (1500 RPM) for Different Lubricants.
N_2=Undoped Mineral Oil.
S_1 (Dotted Line)=Mineral Oil Containing a Sulfur-Type Additive.
F_1=Castor Oil.
P_1=Mineral Oil Containing a Phosphorus-Type Additive.
S_1=Mineral Oil Containing a Sulfur-Chlorine-Type Additive.

Conclusion.

The various indexes developed for giving a single-valued rating of E.P. oils by the Four-Ball Extreme-Pressure Lubricant Tester all suffer from the drawback that some aspects of the data which may be obtained are ignored. None of the methods pays much attention to the coefficient of friction before, during, or after seizure, and none of them involves wear or welding pressure. It would seem preferable to establish the minimum wear-load curve for a satisfactory lubricant and then rate oils on the extent to which they exceed these minimum values.

The Four-Ball Wear Machine

Most machinery operates at loads considerably below those at which seizure occurs. The Four-Ball Extreme-Pressure Lubricant Testing Apparatus is built rigidly in order to accommodate the very high loads necessary to cause seizure and welding of the balls and, because of the heavy construction, it is insensitive to low loads. The Four-Ball Tops permit measurement of either friction or wear under moderate conditions of load, but both cannot be measured simultaneously. Moreover, since neither of these machines is designed for routine tests of long duration, a different type was built in these laboratories for the study of lubrication under conditions less severe than those which lead to seizure. This apparatus, called the Four-Ball Wear Machine, was briefly described in an earlier paper[2]. It is adapted for routine measurement of both wear and friction at controlled temperatures, speeds, and loads.

A six-unit Four-Ball Wear Machine is pictured in Figure 13 (front

cover) and a single-unit "drill-press model" utilizing the same mechanical arrangement in Figure 14*. The principle part of the machine is the ball-holder assembly shown in Figure 15 which provides for heating and the recording of temperatures, the requisite electrical leads being brought out through frictionless mercury contacts. The loading pillar for the lower-ball holder and the device for rotation of the ball holder under frictional torque are also shown. The loading arrangement is clearly seen in Figures 13 and 14. Each beam and empty tray is exactly balanced by ball-holder, thrust bearing, and loading pillars; the fulcrum is so placed that the loads delivered to the ball holder are ten times those applied to the tray.

The friction indicator (Figure 16) consists of a calibrated nickel-plated steel spring connected at one end to the torque arm and at the other end to an adjustable support. The extension on the spring is measured on an arbitrary scale by a revolution counter geared to the spring support.

The machine is capable of operation over a wide range of conditions, viz., loads from 100 grams to 50 kilograms, speeds from 250 to 4000 rpm, temperatures from 30 C to 230 C. The test specimens, one-half-inch balls ,may be of any available metal and may be plated with such metals as copper, gold, or silver.

Procedure for Determination of Wear

After consideration of the variables of load, speed, time, and temperature, the conditions adopted for rating wear of various lubricants are as follows: two-hour duration; 700 rpm; 130 C; 7-kg load. At the end of the test wear is indicated by size of the wear scar. The diameter of the wear scar is conviently measured with a low-power microscope such as the Bausch and Lomb textile binocular microscope equipped with a Falex micrometer eyepiece. It is preferable to make the measurement before the balls are removed from the holder to aid in locating the scars. The scar will thus appear as an ellipse when viewed with the barrel of the microscope parallel to the axis of the ball holder; therefore the major axis must be taken as the diameter. The average diameter of the three scars in each unit is tabulated as the scar diameter of the unit.

Obviously there may be times when other test conditions will be desired. Temperature and load are the variables usually adjusted and sometimes a whole range should be studied. The temperatures generally taken are 30 C, 80 C, 130 C, 180 C, and 230 C, although 130 C gives the most reproducible results. Loads

* *A single-unit Four-Ball Wear Machine is available from the Precision Scientific Company, Chicago, Ill.*

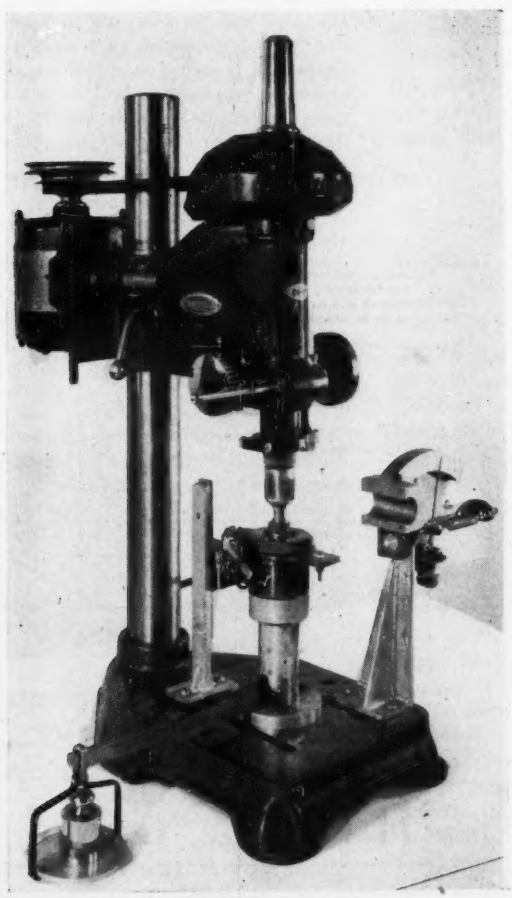


FIGURE 14
Drill Press Model Four-Ball Wear Machine.

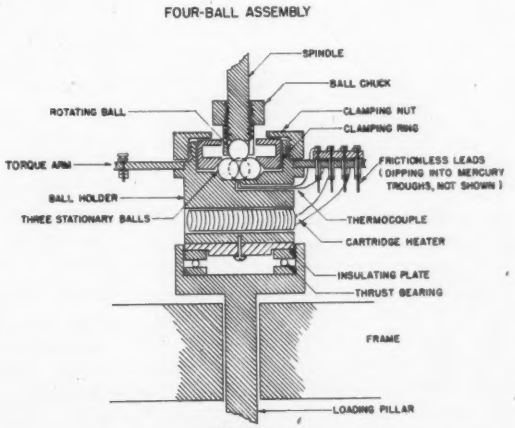


FIGURE 15
Four-Ball Wear Machine.

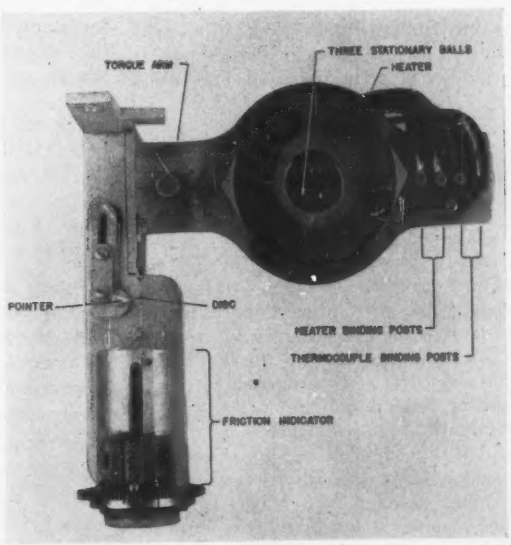


FIGURE 16
Four-Ball Wear Machine, Ball Holder and Friction Indicator.

most frequently used are 1, 7, and 15 kg. Two hours is a convenient time and is justified on the basis that at this point wear is a linear function of time. The use of higher speeds does not alter the results qualitatively. Reproducibility depends upon the type of lubricant, load, and temperature. However, since the process of wear is determined by many factors including surface finish, hardness, and cleanliness of the balls, it is well to make at least duplicate determinations. When wear on any unit differs consistently from the values in other units, the trouble can usually be traced to a defective spindle bearing.

The earlier paper (2) describes in detail the kind of information on wear which can be obtained, but one example will be given here. In Figure 17 are presented data on wear versus load for two undoped mineral oils and two oils containing antiwear additives. It is evident that a high-viscosity aircraft-type mineral oil gives better protection against wear at low loads than does a motor oil of lower viscosity, in agreement with results on wear of piston rings in test engines. Furthermore, sulfurized sperm oil, which is often used to prevent excessive wear and scuffing under moderate conditions of load, is seen to be mildly effective in reducing wear. Tricresyl phosphate, a common antiwear agent, gives very low wear at low loads but, from the slope of the curve, does not appear effective at high loads, again in agreement with general experience.

The above data illustrates the type of information which can be obtained with this machine. Considerable fundamental information on the mechanism of wear already published[2] has been obtained and use on a routine basis established.

The Measurement of Friction

During the two-hour wear test the torque on the ball holder is generally recorded every ten minutes and the coefficient of friction can be computed. However, if friction is of primary importance this procedure has the disadvantage that, because of the constantly changing values of pressure at the rubbing surfaces (as wear progresses), friction is dependent upon wear. Consequently, a procedure was adopted which involves control of pressures by operating with preformed wear scars of known area. Mineral oil is first used as a lubricant for periods of 1 to 120 minutes to form the scars and then replaced by the test

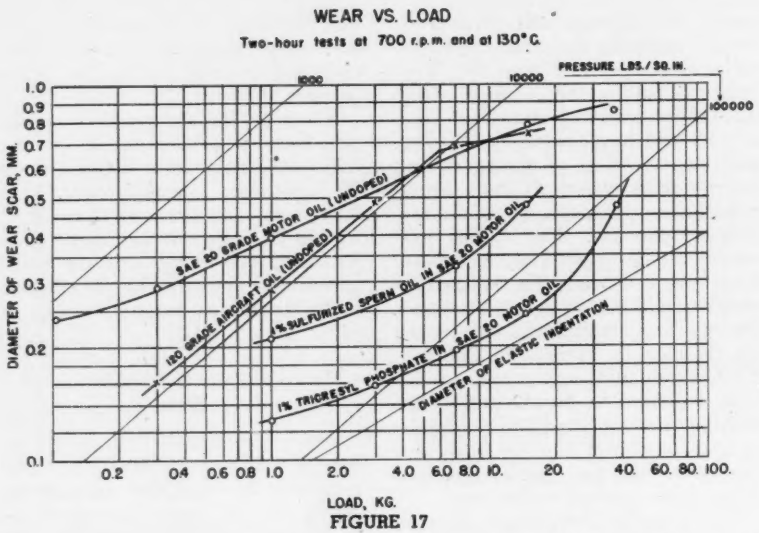


FIGURE 17

oil; on subsequent operation for a short time (30 minutes), curves of the type shown in Figure 18 were obtained. Since some wear occurs during the 30-minute friction test, as indicated by the length of the arrows connecting the smallest initial scar diameter to that observed after the friction test on this scar, the effect of wear is not completely eliminated. However, by running for shorter periods of time (e.g., one minute) either on new balls or on those with performed scars, friction readings can be made up to very high pressures (over 200,000 psi) without being appreciably affected by wear. Again, the conditions chosen for study depend upon the correlation it is hoped to establish.

Figure 18 shows the beneficial effect of acids on the coefficient of friction of mineral oils even though wear is high. It is also seen that tricresyl phosphate is without effect on friction, although effective in reducing wear. A mixture of a friction-reducing additive and a wear-reducing additive does not give both low friction and low wear since the two functions are competitive, as has already been described.[2]

The Four-Ball Top

The Four-Ball Top is an adaptation of the four-ball bearing principle to a machine for measuring the coefficient of friction at low sliding velocities and high pressures. It was developed in its original form by Boerlage and Blok[6], and is shown alongside the chronograph in Figure 19. Briefly, it consists of a weighted top which is arranged symmetrically around a single steel ball, which in turn rotates in a cradle formed by the three lower clamped balls. Since

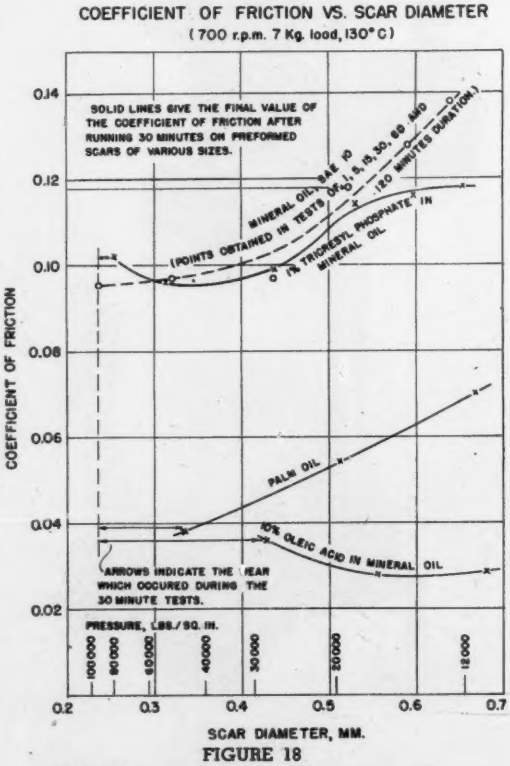


FIGURE 18

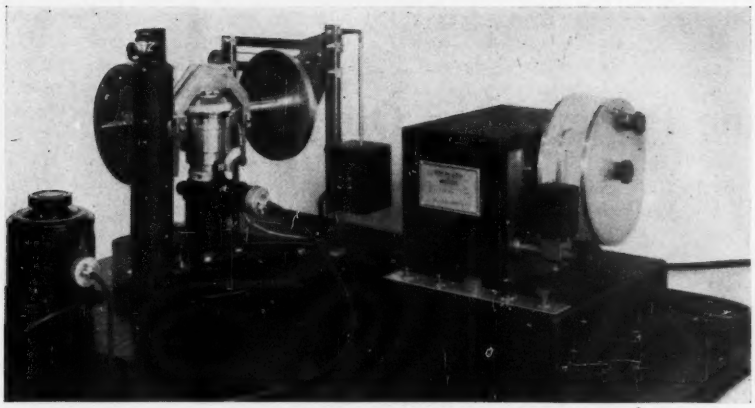


FIGURE 19
The Four-Ball Top of Boerlage and Blok.

the top is free-wheeling, only the frictional force between the upper and lower balls is involved in retarding the motion. Thus, to obtain coefficient of friction it is only necessary to determine the time and number of revolutions until the top stops spinning, once it has been given a definite angular velocity by a falling weight. The coefficient of friction, f, can be calculated by the equation,

$$f = C\,(n/t^2),$$

where: n is the number of revolutions,
t is the running time of the top,
C is a constant depending upon the weight and moment of inertia of the rotor and the size of the balls.

This machine is very useful for studying the fundamentals of lubrication. Beeck and co-workers[7] have developed a drum recorder shown together with the modified top in Figure 19 so that a careful analysis of the motion of the rotor over the whole range of velocity can be made. The recorder serves as a chronograph and receives its impulses from a photoelectric cell, the illumination of which is interrupted by the motion of the rotor. From these records the angular displacement against time is plotted, and instantaneous values for velocity and deceleration can be readily obtained by graphical differentiation. The coefficient of friction is then calculated by equating the observed decelerating torque to the frictional moment. Finally the coefficient of friction is plotted against velocity.

Figure 20 shows typical data obtained with the four-ball top described above which are highly significant, since they indicate that, at a certain critical and easily reproducible velocity, the curves bend over sharply and the coefficient of friction becomes constant, that is, independent of velocity. Undoped white oil does not show this effect but, when a small amount of oleic acid is added, the bending of the friction-velocity curve is very sharp. The region below the critical velocity was characterized as the region of true boundary lubrication, while the region above the critical velocity was termed "quasi-hydrodynamic" for it seemed evident that the lowering of the co-efficient of friction at the higher velocity was due to oil drag or a "wedging effect." By means of this apparatus, the effect of various polar molecules on the critical velocity and magnitude of the coefficient of friction was studied.

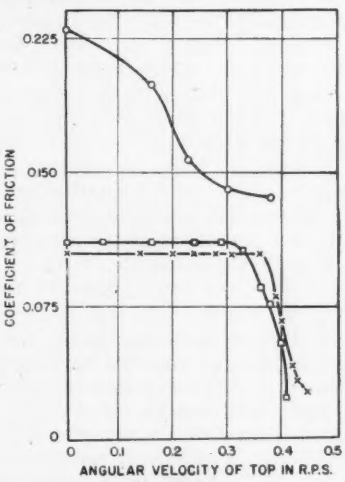


FIGURE 20
Friction as a Function of Velocity in the Four-Ball Top.
O=White Oil; X=U.S.P. Oleic Acid.
□=White Oil + 1% Oleic Acid.

The Four-Ball Wear Top

A motor-driven modification of the Boerlage Four-Ball Top was developed by Beeck and co-workers (cf. Figure 21) which permits the measurement of friction by the deceleration just described and also the measurement of wear by sustained operation for several minutes or hours. The rotor is motor-driven and can be brought up to the desired speed and then disengaged from the driving mechanism by means of a ratchet. For kinematic studies of boundary friction the deceleration of the rotor is observed by means of a photoelectric chronograph which receives its impulses via a decagonal mirror attached to the upper part of the rotor. The three lower balls are also insulated and provided with separate contacts which permit the conductivity to be determined when the current passes from one lower ball through the top ball and back to second lower ball.

Since the data of Figure 20 indicate that even under high pressures and low speeds oil is wedged between the contacting surfaces, it was interesting to check this result with the Four-Ball Wear Top by measuring the electrical resistance between the upper and lower balls. Rather striking confirmation of the data based on the friction measurement was obtained. Thus, when the rotor was brought up to high speed the resistance was found to be very high (over 10,000 ohms). As the speed became slower the resistance de-

(Continued on page 59)

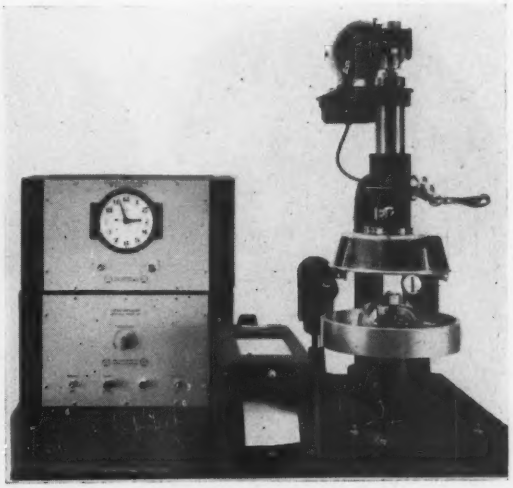


FIGURE 21
The Four-Ball Wear Top.

Engine Preservative Oils

By HELEN SELLEI-BERETVAS
Nox-Rust Corporation

AMONG the most recent of the large variety of additives used for improving the quality of internal-combustion engine lubricants, are rust preventitives or corrosion inhibitors. Oiliness agents, pour point depressants, viscosity index improvers, detergents, antioxidants and also extreme pressure agents, have been discussed considerably in the technical literature of the past few years. In addition to numerous patents and articles, several authors have given a summarizing account of these materials.[1] [2] [3] [4]

The Nature and Chemistry of Corrosion Inhibitors As Used In Lubricating Oils

The nature and chemistry of corrosion inhibitors as used in lubricating oils are very different in many respects. Until recent times the corrosion inhibitors were classified as a branch of antioxidants, but it was recognized that theories that apply to antioxidants may not give sufficient explanation for the mechanism of all inhibitors developed. It was believed that these inhibitors substantially passivate the catalytic action of the metal on oils in the engine. Such materials would be various phosphite, arsenic and antimony compounds as well as chromium compounds.

Suggestions have been made by many authors, mostly in the form of patents, for inhibiting corrosion. It is not possible to give a complete review of these patents in this article, therefore only a few illustrations are given.

A. P. Anderson increases the wetting capacity of mineral lubricating oils for corrosion preventive purposes[6] with addition of a chlorinated hydrocarbon wax-amine 0.25-5.0% and a carboxylic acid of at least 12 C atoms in amounts of 0.1-2.0%.

R. E. Burk recommends for the same purpose 0.25% of diamino-diphenylmethane derivatives containing the group

$$N=\langle\bigcirc\rangle \quad X \quad \langle\bigcirc\rangle=N;$$

where X is C, N, S, O, P, Al, B, As or Sb.[7]

E. W. Cook and W. D. Thomas, Jr., inhibit corrosion in heavy duty internal-combustion engines with special alloy-bearings by mixing in the oil 0.1-3% of a product obtained by heating an oil soluble petroleum sulphonate with P_2S_5 until the evolution of H_2S has ceased.[8]

For inhibiting corrosion of cadmium silver bearings in internal-combustion engines, D. E. Badertscher, G. S. Crandall and F. M. Seger are using 0.05-2% of a naphtyldiphenyl methyl thiocyanate or other thiocyanates of a given general formula.[9]

Intake Valve, Exhaust Valve and Spark Plugs from L-4 Test on AXS—934.

A British patent suggests incorporating in the lubricating oil a bearing corrosion inhibitor consisting of a mixture of various cyclohexyl phosphites.[10]

The examples mentioned may illustrate the possible variety of chemical compounds that can be used successfully as corrosion inhibitors in lubricating oils.

To the present time there are no generally recognized physico-chemical laws that govern the mechanism of these substances. But there are standards in the form of Government specifications which give the objectives that can be obtained by incorporating the proper inhibitors in lubricants which may serve as engine preservative oils.

The Army and Navy have been equally interested in the development of a proper preservative oil for automotive and airplane engines. Because of the complexity of the subject, reference will only be made to specifications set forth by the U. S. Army for automotive engines.

Three Phases of Development In Engine Preservative Oil

In the development of preservative lubricants three phases are distinguishable. In the first phase the preservative oil was filled in the engine and kept there exclusively for rust preventive purposes during storage and transport. It was drained off bfeore the motor was set in operation. At this time a motor oil was filled in. It was not necessary to wash the motor between these two operations. The rust preventive which was still present after the draining was expected to blend entirely with the lubricating oil. It could not contain anv constituents that would have been harmful to the motor in operation, but still the preservative oil by itself did not have the qualities of a high-grade lubricant. From the point of lubrication it was only specified that the mineral oil used should be "highly refined" without describing the qualities of the oil any closer. This period was covered by the U. S. Army Ordnance Tentative Specification AXS-674 issued February 2, 1942. This specification underwent a few changes due to revisions. The second revision effective September 11, 1943, changed the original character of AXS-674.

The new form refers to a mineral lubricating oil with additives contained that will take care of the rust preventive functions. No stress whatsoever is put on the quality of the lubricating oil. Even the term "highly refined" has been omitted. While the original AXS-674 oil had to neutralize acid fumes that might develop in the motor, the revised edition did not require this quality any more. This revision was considered satisfactory for the purpose for which the preservative oil serves and went into effect as a U. S. Army specification (not tentative) under #2-122 in 1944.

The second stage of development is that of the present usage. The rust preventive oil is also expected to have excellent qualities as a lubricant in automotive engines. It will not be drained from the motor before setting it in operation. The preservative oil will be replaced by a lubricating oil from time to time. The requirements for this double-purpose oil are given in Army Ordnance Tentative Specification AXS-934, issued April, 1943. The idea is that whenever a preservative oil is required that shall also have high lubricating qualities, a material shall be used that complies with AXS-934 and not AXS-674. On the other hand, in cases when only the preservative qualities are important, e. g,. long storage, and when the lubricating part might be neglected, AXS-674, Revision 2, can be applied. The consequences of this conception were that in many cases AXS-934 replaced AXS-674 oils. At the same time, by changing the humidity protection requirement from 200-hours to 300-hours in Revision 2 of AXS-674, this oil could find application where previously some other type of rust preventive was used.

The third phase in the development of engine preservative oils will be reached when corrosion inhibiting properties will be incorporated in all engine lubricants. These new inhibitors that are mostly still under development will preserve the metal parts against the corrosive action of possible acidity or sludging during operation and keep all engine parts from rusting at times when the motor is not in operation. The evolution of engine preservative oils involves the changes that are necessary to transform an oil that was used in storage only into an oil serving as a lubricant in internal-combustion engines.

Description of Preservative Oils As Required in Specifications AXS-674* and AXS-934

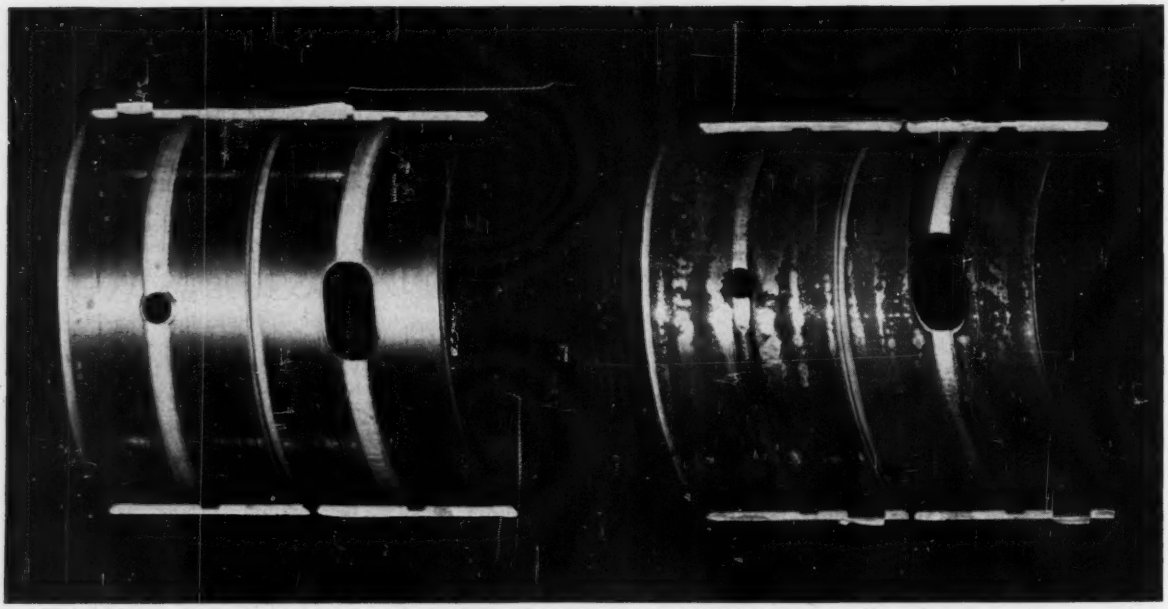
The specifications cover a properly inhibited mineral oil in two viscosity ranges, the light or Grade I being an SAE-10 oil and the medium or Grade II an SAE-30 oil. Both specifications have in common requirements for neutralization of hydrobromic acid and protection in the humidity cabinet at 100 F and 100% relative humidity for at least 200-hours on sandblasted SAE 1020 steel. These oils also have to protect coated plates when immersed in salt water for a minimum of 20-hours.

The oils shall not be corrosive to non-ferrous metals. In this respect laboratory requirements of AXS-674 were relatively more severe than those of AXS-934. The former established a test of one week's duration, limiting the change in the weights of metals after this period to 25 mg. The test was carried out with 2" x 4" x 1/16" metal panels in separate beakers for each metal such as magnesium, copper, lead and coupled lead-steel panels. The metal had to be immersed to 3/4 of its surface in 160 gm of an emulsion containing 1% water in the oil tested, and exposed to 160 F for one week. In our laboratory we found that giving different additives in amounts of 0.2-4% to a basic rust preventive oil will influence the weight of the metal panel tested quite considerably.

**This survey refers to the original unrevised edition.*

Change in weights of metal panels in mgs. after one week's storage at 160 F.

	Lead	*Magnesium*	*Copper*	*Lead-Steel Coupled*	
Basic Rust Prev. A.....	—6	+1.5	—1.5	—6	+1
A+1.0% org. amine of the morpholine type	—4	+12	—5	—5.5	—1
A+1.0% of a Phosphite-Phosphate type inhibitor.....	—54	+8	+1	—54	+0.5
A+0.2% Oxidized petroleum neutr. no. 35 mg K6H/g.....	—21	...	...	—24	—0.5
A+0.5% Sodium soap of carboxylic acids cont. 16-18C.....	—15	+5	...	—19	—0.5
A+0.5% Aerosol OT	...	0	...	—6	0



Satisfactory and Corroded Copper Lead Bearings from Chevrolet Test on AXS—934 Oil.

This "effect on metals" test was entirely omitted in the later revisions and replaced by a qualitative copper corrosion test of three hours duration at 210 F.

The fact that Specification AXS-934 did not specify even the copper corrosion test in its requirements does not mean that the inhibitors used in this oil might be more corrosive to non-ferrous metals than those in the AXS-674. While AXS-674 oils were ready for acceptance whenever they passed the requirements, all of which could be tested exactly in a well-equipped laboratory for rust preventives, the AXS-934 oil requires a 36-hour Chevrolet Engine test before it may be approved.

If we consider the intent of each of these specifications, it is not hard to understand this basic difference. AXS-674 is a rust preventive oil. AXS-934 is a rust preventive lubricant. This difference in application makes it evident that AXS-934 must contain much higher quality ingredients than AXS-674.

Importance of Engine Test On Preservative Lubricants

It is quite possible that a rust preventive oil which will serve very well under static conditions would age and sludge when exposed to high temperatures when used under actual working conditions, as in an engine. This might cause ring sticking, or the formation of deposits or even crusts of a very undesirable nature that would make the operation of a motor entirely unsatisfactory if not impossible.

Some authors stress the merit of lacquer films formed during operation[12] and wish to omit detergents that interfere with this action.

In any event only an actual engine test is sufficient to tell whether a rust preventive will be good enough for use in an internal-combustion engine during operation.

It is well worth while to run an engine test on a lubricating preservative oil before using it on a wide scale. The dissembled motor will give evidence of any corrosions, sticking, deposits or sludging that might have occurred during the test. This method, although laborious and expensive, is still far more economical than putting a product on the market which might spoil beyond repair a series of engines before its failure could be detected.

The question arises regarding how it could be determined in advance whether an oil which passes all protection requirements will pass or fail in the Chevrolet Engine test.

Some publications give account of efforts made in this line by differentiating between potential and existent corrosion[13] and mention some appropriate laboratory apparatus which could effectively duplicate the process of aging that would take place in service.[14] In these papers correlation is made between the given laboratory results and the Chevrolet engine test.

On the other hand there might be some correlation between the Underwood testing machine and the Chevrolet engine test. However, this possibility is frequently disputed by experts who are equally familiar with both of these two testing procedures.[15] A reliable correlation between the engine test and some other method of testing that can be conducted in the chemical laboratory which has no engines at its disposal, would be of great help to the research chemist dealing with these problems.

Our laboratory was conducting extensive testing using the Underwood machine in connection with engine preservative oils. Some of these materials were also tested in a Chevrolet engine. It was found that oils that stood up well in the Underwood tester had a greater possibility of standing up in the 36-hour Chevrolet engine test than those that failed in the Underwood test. References are made only to the change in the oil after 10-hours in the Underwood tester, because any combination which might affect the bearings adversely was automatically eliminated.

The viscosity changes after 10-hours in the Underwood tester are in close relation to the oils' stability at the testing temperatures. Whenever the change is small the stability of the oil is higher. It can be assumed that this is a very important factor under service conditions. Even if there should be no direct correla-

tion between the two testing methods, the stability factor observed during the Underwood test can serve as an indicator that a preservative oil will have a better chance to pass the much more severe Chevrolet Engine test than an oil which failed in the Underwood machine.

The AXS-934 specification, by requiring the Chevrolet Engine test, assures the high quality of the preservative lubricant. The engine test also tests the preservative oil's action on non-ferrous metals found in the various bearings. Considering the severe conditions of this test, the high temperature and the long duration. it is understandable that the "effect on metals" test of AXS-674 has been omitted.

Relation of Corrosive Inhibitors To Lubricating Qualities

There are two important factors that play an important part in engine preservative oils: the mineral lubricating oil and the corrosion inhibitors. It is evident that high quality of both of these ingredients will assure best results in an engine test. The grade of refining together with the viscosity index determine the quality of the lubricating oil. The inhibitor, on the other hand, must be properly selected with regard to the oil used, as different mineral oils require different inhibitors in order to exert similar rust preventive actions.

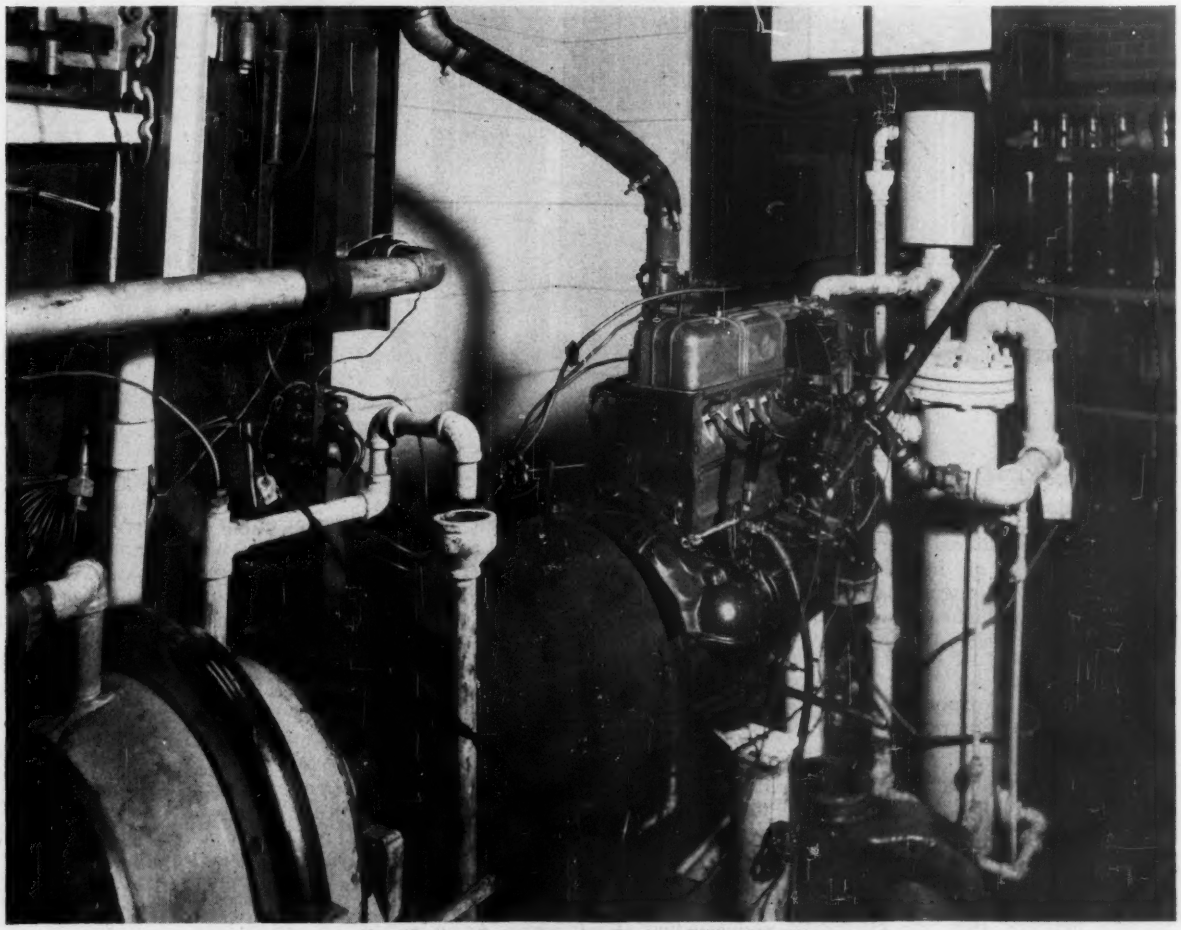
It is very likely that engine preservative oils containing higher amounts of a certain type corrosion inhibitor will give better service results than those with lower amounts of the same inhibitor. The difficulty in giving any proper proportions as to the amounts to be used arises from the fact that there are different ways in giving identical rust preventive qualities to a certain type of mineral oil.

Some inhibitor groups have to be applied in larger quantities than others. For obtaining the required qualities the inhibitor has to be present in just the proper amount, and that can only be determined by experiment. Too much of the inhibitor can eventually do just as much damage as too little. But this still does not tell how much of it should be used.

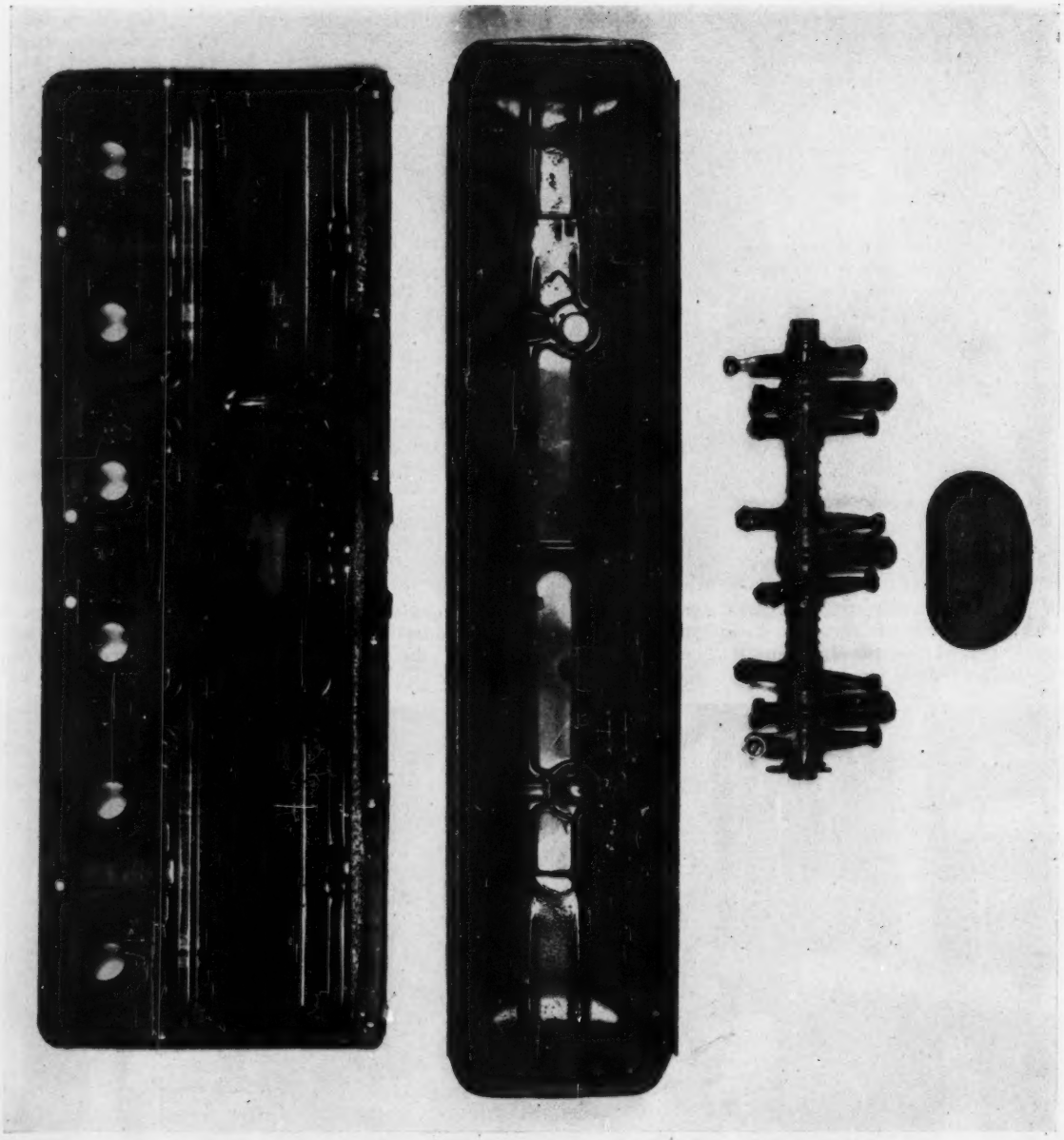
The experiments for finding these proper amounts show that there usually is no one definite amount in applying corrosion inhibitors, but rather a reasonable range for the inhibitors within which they will provide satisfactory protective action.

From the economical point of view, it is always important that the research laboratory shall find out exactly, by thorough investigation, the lower limits of any possible inhibitor group. When this is known, it can easily be decided what amount shall be applied in a definite case. This amount shall represent a fair safety factor without causing any unnecessary waste.

Based on practical experience, it might be assumed that an oil containing inhibitors in an amount close to the higher limit of the range will give better results in the engine test than those containing amounts which are only absolutely necessary to meet the protection requirements.



Test Engine Apparatus for Testing AXS—934 Oils.



Push Rod Cover Plate, Rocker Arm Cover, Rocker Arm Assembly and Oil Sump Screen from L-4 Test on AXS—934 Oil.

Since a lower viscosity oil usually requires more inhibitors than would a higher viscosity oil, its likely that the SAE-10 grade engine preservatives will contain higher amounts of inhibitor than the SAE-30 grade oils.

Fulfillment of Specification Requirements

Besides the humidity protection and engine performance there are a few more requirements set for AXS-934 oils.

The question arises as to how all these problems can be solved in a simple but efficient way. It frequently happens that the chemist who worked on one part of the problem finds all his results upset as soon as he starts to change his material in order to meet different requirements of the same specification. To give a practical example, there are many chemicals that will neutralize the action of hydrobromic acid but will at the same time interfere with protection in the humidity cabinet.

Experiments show that certain rules must be followed in selecting the proper inhibitors which will give protection in an atmosphere of 100% relative humidity. Some other inhibitors might be required to protect the metal against the very corrosive action of salt water. Again a different group will take care of the acid fumes which might be generated during service.

It is very important, therefore, that the chemist be thoroughly familiar with all the details of the problems. This will help him to reach solutions from a general point of view. It will make it possible that the solution of each question will not be based on a single material but will cover a theoretical solution into which a variety of inhibitors might fit.

If the general solutions for each requirement are known it will be possible to develop a preservative

(Continued on page 59)

Limitations of Greases for Bearing Lubrication*

By H. A. McCONVILLE

Schenectady Works Laboratory, General Electric Company

GREASES for industrial use have been found by experience to have certain limits for their applications. The following discussion is based on practice with electric motors and also on aeronautical and marine apparatus.

1. Consistency or Stiffness

Opinions as to desirable consistencies of grease for various applications vary. We do issue grease specifications which set our company standards. At present we call for an A.S.T.M. worked consistency of 265 to 295 for our ball and roller bearing grease. We recommend this grease for general use in Conrad type bearings or those shielded on one side. We believe it could be as soft as 310 but have set our limits to meet Navy specification 14-L-3 INT. The method of application of the grease will limit the range in consistency that can be used. If the grease is to be applied with a pressure gun by hand, we think that 250 to 260 unworked consistency is as hard as can be used without exerting excessive pressure, assuming the oil in the grease is not of high viscosity. Recently, a grease of 270 unworked consistency containing an oil with a viscosity of 105 at 210 F was so hard to apply that over one hour was needed to fill a bearing housing with a hand Alemite gun. Under these circumstances we might want 280 unworked consistency or softer.

Where roller bearings are involved, we find it necessary to keep the grease on the soft side, as near 300 consistency as possible. If the grease happens to contain much air, the consistency should be watched much more closely. Under these conditions if the grease is softer than 315 to 320 consistency, it may thin down on working in a bearing and run out. If stiffer than 275, it may harden excessively in the bearings as the air comes out of the grease.

2. Temperature Limits

Our temperature limits for calcium base grease are 150 F for continuous operation and 175 F for intermittent operation on the high side; for sodium or sodium-calcium base greases 175 F for continuous and 200 F for intermittent operation. Lithium base greases may vary from 160 F to as high as 250 F to 275 F for continuous operation and 25 F higher for intermittent operation. We haven't had enough experience with barium or strontium bases to predict safe limits on the high side with these greases.

On the low side, the average grease will be good down to —20 to —25 F. The lithium low-temperature greases seem to be good for —67 F when used in airplane control bearings, which turn slowly and are rotated at intervals or in applications where there is a large amount of torque available. If bearings are in apparatus exposed to low temperatures for several hours before turning, with only low available torque, —35 to —40 F may be the limit. Instances have been reported where 0 F was the low safe point for these greases.

3. Speeds

The speed with which a bearing rotates is a factor. Bearings have been run successfully at 26000 rpm using grease. If the figure of 65000 rpm is right for the maximum speed for ball bearings, then oil lubrication is needed for speeds in the higher ranges. This is often applied in the form of a spray or mist. Sometimes a large bearing running slowly at 450 to 600 rpm, may break a grease down excessively and thin it out. In general a special type of grease is needed for speeds over 5000 rpm.

4. Size of Bearings

Ball bearings as large as No. 322 at 1800 RPM or No. 326 at 900 rpm have been used at the Schenectady Works for grease lubrication of motors for intermittent service. Under special conditions larger sizes have been used in other plans.

5. Oxidation Resistance

Chemical stability or resistance to oxidation may in some cases be a limiting factor. This is especially true of sealed-for-life bearings, in which case the grease must be very stable. It is also important in other bearings in apparatus which may remain inactive for several years. If the grease oxidizes badly, its flow point may be lowered to the extent that it will leak out of the bearing. Oxidation also affects the low-temperature operating limits of a grease, lessening the range in extreme cases by 30 F or more. The use of anti-oxidants in grease is quite common today, but to find good ones that are not driven off too easily at high temperatures is a problem.

(Continued on page 60)

**Originally prepared for presentation at the A.S.L.E. Convention scheduled for February 8, 1945, in Chicago, but postponed at the request of the Office of Defense Transportation.*

New Developments In Lubricants For Refrigeration System Compressors

By EDGAR S. ROSS

Sun Oil Company, Philadelphia, Pa.

IN a series of four previous papers presented before various local sections of A.S.R.E., complete fundamental data were assembled covering the following subjects:

1. Petroleum—basic source of lubricating oils.
2. Processing of crude petroleum.
3. Constitution of lubricating oil distillates.
4. Refining of lubricating oil distillates.
5. Properties of lubricating oils.
6. Lubricating oil uses.
7. Discussion of miscellaneous subjects intimately related to lubricating oil characteristics and uses.

Since these basic subjects have recently been thoroughly covered, readers are referred to the available literature and this paper will concern itself mainly with the characteristics and availability of lubricating oils to meet present-day requirements in the refrigeration industry.

With the introduction of hermetically sealed units, there came a very definite demand for oils of improved stability characteristics. Since it was no longer a simple procedure to replace oils that had "gone bad" in service, it became necessary to develop oils that would remain satisfactory for the entire life of the units themselves.

Secondly, the development and use of the new type of refrigerants known as Freons, introduced an entirely new condition of relationship between oil and refrigerant.

Whereas there was no mutual solubility between oil and such refrigerants as ammonia, sulfur dioxide and carbon dioxide, the picture became one of complete solubility in Freon. This quite naturally brought about a new consideration of viscosity of the oil and the effect on viscosity of dilution with refrigerant. In the earlier cases, lubrication was provided by a mixture of oil and refrigerant with practically no change in the viscosity condition of the oil, but with the new refrigerants lubrication depended entirely on a solution of oil in refrigerant whereby the initial viscosity of the oil was greatly reduced.

Thirdly, the ever growing demand for lower and lower temperatures in various industries introduced new service conditions for refrigerating equipment which, combined with certain mechanical changes in equipment, revealed a "weakness" not heretofore experienced with compressor lubricating oils. The combination of solvent-extraction properties of new refrigerants and low temperature operations resulted in so-called "wax separation" with resulting difficulties due to stoppage of capillary tubing and expansion valves, as well as fouling of condenser and cooler walls.

With reconversion well under way and a pent-up demand for its products promising a volume of production greater than ever before, the oil requirements of the refrigeration industry are a matter of timely interest. Dr. E. S. Ross, A. S. L. E. Member, presented this paper at the 32nd Spring Meeting of the American Society of Refrigerating Engineers. The meeting, complete with discussions of papers, was held in print, and this paper is reprinted, with permission, from the August 1945 issue of "Refrigerating Engineering", official publication of the A. S. R. E.

Present Essential Characteristics of Compressor Lubricating Oil

THE overall changes in units, refrigerants and operating requirements created a definite demand for oils of greatly improved characteristics. These new demands, supplementing former quality requirements, may be summed up in the following list of essential and desirable characteristics which must be given full consideration in the selection of proper compressor lubricating oil.

1. The oil must maintain sufficient body in upper temperature range, alone or admixed with refrigerant, to provide adequate lubrication to moving parts and provide proper seal where required.

2. The oil, or oil-refrigerant mixture, must have proper fluidity to form an effective oil film and provide adequate lubrication at lowest temperature encountered in service.

3. The oil must not react adversely with the refrigerant and must separate rapidly from the refrigerant.

4. The oil must not contribute to sticky, waxy deposits under low temperature operating conditions.

5. The oil should have extremely low pour point to facilitate drainage from non-lubricating zones into which the oil is carried incident to operation of the system.

6. The oil must be neutral and remain so in service, resisting formation of corrosive compounds.

7. The oil should be free of carbonizing tendency when exposed to so-called "hot-spots" which sometimes develop in early operating service.

8. The oil must be free of any excessive moisture content, and should contain only the minimum moisture consistent with careful handling.

9. The oil must possess unusual degree of stability in service, thus assuring "long life" service without change or breakdown.

10. Last, but not least, the oil should possess all of the above characteristics for use on an entirely practical and economic basis; in other words, the oil must not be too expensive for economical use.

Typical Specifications for New Oils Now Available

NEW oils are now available which meet the rigid requirements enumerated above, in viscosity grades covering sufficient range to meet all normal equipment requirements. Typical specifications for new regular and special oils now available are given as follows:

	A	*B*	*C*	*D*
Gravity-API/60°F. Approx.	21.5-23.5	21.5-23.5	20.4-22.4	20.4-22.4
Flash, ASTM open cup	330-340°F.	330-340°F.	350-360°F.	350-360°F.
Fire	370-390°F.	370-390°F.	400-420°F.	400-420°F.
Viscosity - S. U./100° F.	150-160	150-160	280-300	280-300
Color—N.P.A.	1½-2	1 Max.	1½-2	1-2
Pour test—ASTM	—35°F. Max.	—35°F. Max.	—25°F. Max.	—25°F. Max.
Neutralization No.—ASTM	Neutral	Neutral	Neutral	Neutral
Sligh oxidation—ASTM	10-20	10-20	10-20	10-20
Steam emulsion number	30-60 sec.	20-50 sec.	30-70 sec.	30-70 sec.
Dielectric strength	25 K.V.Min.	25 K.V.Min.	25 K.V.Min.	25 K.V.Min.
Floc test for wax—Max.	—30°F.	—70°F.	—20°F.	—50°F.

Examination of these specifications will reveal some of the pertinent characteristics discussed above. The gravity, flash, fire and pour points indicate that these are napthenic-base oils. The color, neutralizing number, steam emulsion number and Sligh oxidation indicate the nature and degree of treatment, and the dielectric strength indicates the care exercised in handling, storage and shipment. These are general qualifications apparent from the nature of the tests included in the specifications.

The special qualifications included in the specifications are revealed by further consideration of the test data. For instance, the Floc test (a mixture of 10 per cent oil and 90 per cent Freon-12, gradually cooled until wax separates) must now be considered as one of the most important tests, since it is a direct measure of the tendency for "wax separation" from oil-refrigerant mixtures under low temperature operating conditions. The superior suitability of Oil "B" over Oil "A" and of Oil "D" over Oil "C" is indicated by the lower temperature obtainable before wax begins to separate from refrigerant.

The standard test determination of wax in oils is the MEK (methylethylketone) extraction test run at —10 F. Some efforts to produce satisfactory oils were based on dewaxing of the oil to show a low wax content when determined by the standard MEK procedure. This proved to be very unsatisfactory since it was later shown that little, if any, relationship existed between wax values by MEK method at —10 F and performance at low temperature in actual units. This difficulty was eliminated by running the MEK test at —35 F, or lower, which gives results that can be correlated with the service performance, so that oils may be partially evaluated on a basis of low wax content by this modified test. Low wax content by the MEK test run at —35 F and low temperature values for the Floc test now give reasonable assurance of freedom from objectionable wax separation at low temperature operation.

In actual service Oil "B" has been operating at temperatures as low as —100 F with Freon-22, fro long periods of time and with complete absence of objectionable wax separation. Similarly, Oil "D" has been operating satisfactorily in systems as low as —80 F with Freon-22 as the refrigerant.

The 25 K.V. min. dielectric strength requirement insures an oil free from excessive amount of moisture. The specified neutralization number is indicative of the complete absence of acid compounds in the new oil. Not shown in the above specifications, but included in the evaluation requirement, the low neutralization number obtained after subjecting the oil to oxidation stability tests indicates resistance to formation of corrosive compounds in service.

The maximum Sligh oxidation value assures sufficient refining treatment and the minimum limit prohibits excessive treatment, the use of maximum and minimum values thus providing for an optimum treatment that will result in a finished oil processing a high degree of stability in service. The Sligh oxidation is a convenient test for measuring stability and has been supplemented by other evaluation "life" tests which demonstrate its reliable use as a specification requirement.

The so-called Roger's stability test for refrigerator oils is a modification of the test described in the *Journal of Industrial Engineering Chemistry,* vol. 19, pp. 308-312, 1927. This test finds practical use in evaluation testing of oils since it is a form of life and oxidation test. Stability of oil is also measured by comparing values for neutralization number, Sligh oxidation, color, etc., obtained before and after the Roger's test. Oils of high stability show very slight changes in these various characteristics whereas oils of poor stability show a wide fluctuation, the degree of change being a good measure of the instability to be expected in service.

Conclusions

THE conclusions to be drawn are, therefore, that oils are now economically available to perform the following functions:

1. Provide sufficient and adequate lubrication when in mutual solution with modern refrigerants.

2. Assure high, continued stability and long life, especially in hermetically sealed systems.

3. Assure freedom from wax deposits in svstems operating at the low temperatures made possible by modern refrigerants.

The following literature is suggested as supplementary reading with this article:

Refrigerating Data Book, A.S.R.E., 1942 Edition.

Thompson, R. J., and W. W. Rhodes, Bul. on "Freon-22," Kinetic Chemicals, Inc.

Ross, Edgar S., "Mineral Lubricating Oils," *Refrig. Eng.,* July, 1942.

Walker, Walter O., and Wm. R. Rinelli, "The Separation of Wax From Oil-Refrigerant Mixtures," *Refrig. Eng.,* Aug., 1945.

Sun Oil Company, Bul. on "Lubrication of Refrigeration and Air Conditioning Equipment."

Discussion (written, since regular technical sessions of 32nd Spring Meeting of The American Society of Refrigerating Engineers could not be held.)

F. Y. CARTER (Detroit Lubricator Company, Detroit, Mich.): Dr. Ross has ably set forth in numbered paragraphs the essential characteristics compressor lubricating oils must have if they are to meet the rigid requirements of improved modern refrigerating systems. In this and previous papers he has pointed out that the new refrigerants, increased compressor speeds, the use of hermetic units, and the increased popularity of ex-

tremely low temperature refrigeration have each in turn presented additional problems to the oil refiner. The comparison of the four new regular and special oils is indicative that a single oil is not economically and chemically suitable for all ranges of operation, and that it is more than ever important that the user be on his toes if he is to avoid trouble which can be traced back to the compressor lubricating oil.

The pour point test and the Floc test for wax are of particular interest to those in the expansion valve field because these two characteristics of lubricating oils have undoubtedly contributed to the erratic operation of expansion valves in extremely low temperature applications. The writer has personally removed expansion valves from systems operating below —70 F and found the low-side volume of the valves to be completely filled with wax. This without question caused expansion valve failures. On one such application the valves were removed from the system approximately six times before the oil was dewaxed sufficiently to allow dependable expansion valve operation. After a few such experiences valve manufacturers began to think seriously of lubricating oils and ways to dewax them before using them at low temperatures. The work done by the Sun Oil Company and others showed that the oil refining industry recognized its problems very quickly and lost no time in producing a suitable oil for this type of application.

The writer's company has more recently encountered another trouble which has been attributed to lubricating oil in the application of the recently announced differential temperature expansion valve for low temperature applications. This valve is constructed with a small manually adjustable by-pass having an orifice of small diameter. The valve will not operate properly unless the bypass is feeding and it has been ascertained that flow through this small orifice ceases when the inlet liquid temperature is sub-cooled to temperatures below —40 F. Failures do not occur when the inlet liquid temperature is held to a minimum of —30 F and the users of this equipment feel reasonably sure that this stoppage results from oil congealing in the small bypass orifice since it is located in a dead pocket in the valve body and possibly allows separation of the oil from the liquid refrigerant. Consequently, it has been advocated by ourselves as well as others that inlet liquid temperatures be limited to 30 F.

Fewer complaints of wax formation at the expansion valve have been received during the last few months and it is most probable that the new lubricating oils available for low temperature work can be held mainly responsible.

A. E. Brewer (The Texas Company, New York, N. Y.) : I can argue but one point in connection with Dr. Ross's excellent discussion of the characteristics which he has outlined for refrigeration grade lubricating oils—his use of the word "neutral" for neutralization number. Elsewhere in the paper, he mentions the latter as though it was a value, even though it might be so low as to be of no consequence. Yet, in his list of tests, he states "neutral" for all four oils. This may be true for all practical purposes; perhaps it is a good idea for others in our industry to adopt instead of stating the laboratory value for the neutralization number—say, 0.01, which indicates practical neutrality.

National Society News

The Nominating Committee of the Society recently made its report with proposed nominees for the new slate of Directors. Mr. D. F. Hollingsworth of Wilmington, Delaware, was Chairman of the Committee, assisted by D. D. Fuller of New York and H. C. Kraemer of Evansville, Indiana.

New Directors, under the By-Laws, are normally proposed by the Nominating Committee and elected at the Annual Convention. However, as the Office of Defense Transportation suspended all Conventions, it will be necessary to elect our new Directors by Letter Ballot.

The names of the nominees cannot be mentioned at the present time as inquiry is now being made of each of the nominees to ascertain whether he is in a position to serve and undertake the responsibilities associated with this important task. At the earliest possible date, printed ballots will be prepared and mailed to the members of the Society for a Letter Ballot. It is hoped that these can be in the mail before the middle of September, following which a Committee of Tellers will count the return ballots and the results of their counts should be available for publication in the October issue along with pertinent data about each of the new Directors. Of the six Directors elected, three will hold office until December, 1946, and three will hold office until December, 1947. The current Board of Directors completes its tenure of office December 6 of this year.

It is hoped that the members will return their Letter Ballots at the earliest opportunity so that the Tellers can make their count and the Society benefit from any additional guidance they may offer.

The very careful work the Nominating Committee has done in analyzing the background, experience and potential abilities of each of the nominees is certainly worthy of commendation. It is, of course, the privilege of any member of the Society to vote for his own choice and space will be provided in the Letter Ballot for this purpose.

News Item

We have just learned that E. C. Petry, who was co-author with N. C. Penfold of the fine paper which appeared in our June issue, entitled "A Survey of Evaluation Methods for Crankcase Oils for Internal Combustion Engines," has changed his position to become Project Engineer, Fuels and Lubricants, with the Ranger Aircraft Engine Division of Fairchild Engine and Airplane Corporation, Farmingdale, Long Island.

A wheelbearing performance test has been developed to be incorporated into U. S. Army specification 2-108A for General Purpose Grease No. 2, the lubricant used in the wheelbearings of all Army automotive equipment.

The performance test was developed through a cooperative program by the Office of Chief of Ordnance, working with the Grease Advisory Group, Co-ordinating Research Council, whose final report on this work has been circulated to industry.

Sustaining Membership

When the Society set up its various classes of membership, one of the most important classifications was that of the Sustaining Member.

To quote:

"Sustaining members are such persons or organizations as may be interested in or desire to contribute to supporting the purposes and activities of the Society."

The support that industry has given the Society has been very gratifying, and is one of the main factors under which the Society can continue its active and vigorous growth.

It seems appropriate and fitting to list publicly the companies which are Sustaining Members at the present time, but at the same time it should be mentioned that additional companies are in the process of taking out memberships. The following listing of Sustaining Members is given in the chronological order in which the applications were received.

Each Sustaining Member Company appoints one of its members as its official Sustaining Membership representative. At the meeting of the Board of Directors held April 6, 1945, it was unanimously decided that this group of Sustaining Member representatives would be asked to elect one of their members as their delegate and this man would automatically become a one-year appointee as a Director of the Society and in this capacity be able to add his counsel to that of the other Directors and present, to a certain extent, industry's viewpoint on the Board of Directors.

The diversity of the Sustaining Memberships, it is hoped, will always be of such a nature that no single group of interests will dominate this Directorship.

Hodson Corporation
Chicago, Illinois

Inland Steel Company
Chicago, Illinois

L. R. Kerns Company
Chicago, Illinois

Lubri-Zol Corporation
Cleveland, Ohio

Socony-Vacuum Oil Company, Inc.
New York, New York

Dow Chemical Company
Midland, Michigan

Aetna-Standard Engineering Company
Youngstown, Ohio

Farval Corporation
Cleveland, Ohio

Shell Oil Company, Inc.
New York, New York

Tennessee Coal, Iron and Railroad Company
Birmingham, Alabama

Carnegie-Illinois Steel Corporation
Pittsburgh, Pennsylvania

Rex Oil and Chemical Company
Cleveland, Ohio

Lincoln Engineering Company
St. Louis, Missouri

Standard Oil Company of California
San Francisco, California

Aluminum Company of America
New Kensington, Pennsylvania

Sun Oil Company
Philadelphia, Pennsylvania

Stewart-Warner Corporation
Chicago, Illinois

Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

Swan-Finch Oil Corporation
Chicago, Illinois

Republic Steel Corporation
Cleveland, Ohio

Trabon Engineering Corporation
Cleveland, Ohio

NEWS of the S

Cleveland-Youngstown Section

C. A. BIERLEIN, Chairman,
Cleveland-Youngstown Section

At the time of going to press, the announcement of the first meeting of the Section had not yet been issued, but plans are now being completed for a meeting in the early fall.

Milwaukee Section

The Officers and interested members of the Milwaukee Section have been meeting regularly throughout the summer. General Policies, Program, Meeting Place, Committees and Project Outlines all came in for their share of discussion.

Chairman Krause felt that the entire membership should have a voice in Section matters, and the results were very gratifying. The response and willingness of the membership at large to assume responsibility and put their shoulders to the wheel has been surprisingly good. This response has given ample justification to the idea of giving all members the opportunity of actively participating in Society affairs.

Definite plans for the Fall and Winter Programs have been made. Technical meetings will be held on the third Monday of each month. Outstanding films and speakers of note will be combined at each meeting. Dinner will precede each gathering. We all look forward to an active year for the Section.

For matters of record, we are listing the names of the Officers of each of the Sections so that contact can be readily made with the Officers.

Pittsburgh Section

At the business meeting of the Section held April 26th at the University Club, 60 were in attendance and in addition to the election of the Officers listed below, the following Committee Chairmen were appointed:

Program ..... E. B. Svenson, Sr.
Membership ..... L. J. Gray
Entertainment ..... S. M. Fink

On May 25th the Section met at the Hotel Webster Hall and dinner was served to the 59 persons in attendance. In the absence of Dr. Brandes, Chairman Lamport, who opened the meeting, presided, but later turned the meeting over to Mr. E. B. Svenson, Chairman of the Program Committee who outlined plans for future meetings and then introduced Mr. W. E. Kramer of the Gulf Research and Development Company who gave a fine paper on "Experimental Studies of Bearing Performance." Following an interesting discussion and questions period the meeting was adjourned.

The Section held their first Golf and Dinner meeting at the Edgewood Country Club on July 26th. Sixty members and guests attended and a good time was had by all. A "kicker's handicap" between 70 and 80 was run off and the following were the prize winners:

1st Prize—Net 80—H. A. Haas, J. F. Hall, A. J. Taylor.
2nd Prize—Net 79—Wm. Jones, Geo. L. Penny.
3rd Prize—Net 82—J. R. Hewitt, R. M. Gordon.

A fine turkey dinner was served and table prizes, all of which were donated by the members and guests, were won by the following:

C. A. Karthauser
J. M. Moore
P. J. Kavanaugh
J. N. Edwards
C. A. Bodle
R. S. Seely
Chas. Taylor
Geo. L. Rector
D. Strock
J. D. Lykins
T. M. Stonerod
H. R. Mountcastle
M. C. Hazenfield
W. A. Paul
K. K. Stocker
E. E. Ward
R. R. States
James Cambron
H. A. Haas
Wm. Jones
R. C. Withrow
L. J. Gray
E. S. Reynolds
C. J. Ackermann
F. Palmer
H. G. Crumley
Thos. Eberle
W. E. Kramer
Thos. W. Riser

Thanks go to Mr. C. E. Weinkauf, who arranged for the party at the Edgewood Country Club, and to Mr. S. M. Fink, Chairman of the Entertainment Committee, who handled the general arrangements.

SECTIONS

Chicago Section

The Chicago Section is preparing for its active resumption of meetings this Fall. It is thought that these will be held bi-monthly and the first meeting has been definitely scheduled for September 28th with two interesting papers:

"COOLANTS, LUBRICANTS AND THEIR INDUSTRIAL APPLICATION"
By W. A. JOHNSON,
Tractor Works, International Harvester Company, Chicago
and
"SOLVENT EXTRACTED OILS"
By J. W. RAMSAY,
of Socony Vacuum Oil Company.

As in the past, the dinner meeting will be held in Huyler's Restaurant, 308 South Michigan Avenue, and is scheduled to start at 6:30 P. M.

At the May 25th meeting, Mr. M. S. Burg of the Dodge Chicago Plant Division of Chrysler Corporation was elected Vice Chairman of the Chicago Section by unanimous vote.

Mr. Ehret reports that an interesting set of additional papers is being prepared for presentation before the Section. Two papers which will be presented in the near future cover "Standardization" and "Circulating Oil Systems".

Lubrication Engineering

The public reaction to the first issue of LUBRICATION ENGINEERING has been very gratifying, with complimentary letters received by the Officers from all over the country.

Subscription to the magazine, of course, goes with membership in the Society. It is interesting to note that, on the appearance of the first issue, the rate of receiving membership applications took a sudden rise and it is hoped that this rise will continue as there are still many potential members who are not yet familiar with the Society. Corporations, libraries, and individuals are also taking out subscriptions in satisfactory numbers.

The short time available between the appearance of this issue and the June issue has not yet made it possible to solicit advertising to any great extent but it is expected that, before the end of the year, LUBRICATION ENGINEERING will have its merited quota of advertising and present a comprehensive picture of new products to its list of readers.

The editor will welcome discussions about the various papers which have been published, including corroborating and pertinent comments. News of the industry, new equipment, and the like are also welcome material for possible publication and these will be printed if they appear to have general interest and space can be found for them.

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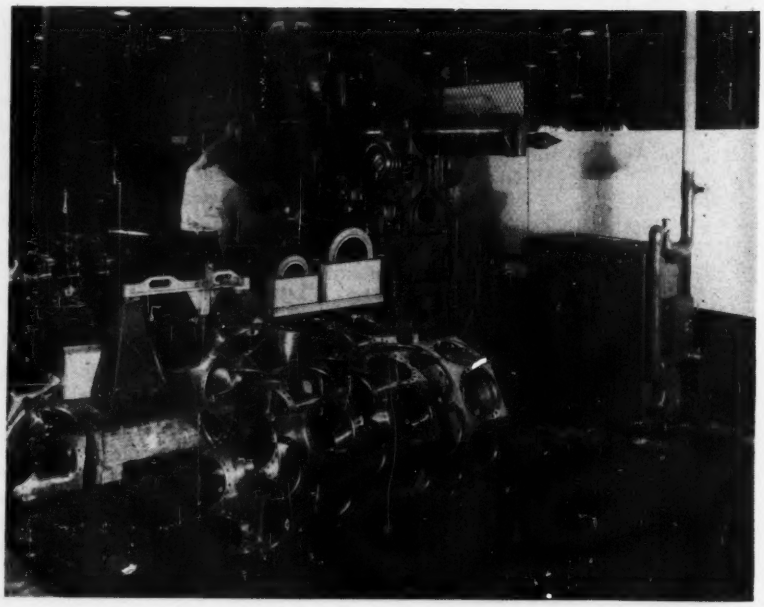
Applications of Liquid Cooling in Machine Tool Operation*

To:
Bryant Heavy Duty Internal Grinder

This machine tool was used to grind a large bore and a small bore in a crankcase. Before a liquid cooler was installed rejects and re-works on this operation ran as high as 10 per cent because of grinding cracks and checks in the workpiece. This was caused by a water-soluble coolant being used instead of an oil. Oil could not be used because it became excessively heated. Reworking the rejected crankcases cost $180 to $240 a day, at the rate of $30 per crankcase.

After a liquid cooler was installed oil could be used and its temperature held at 70° F. There have been no rejects since the cooler was installed, saving $180 to $240 a day in reworking costs. The Bryant Heavy Duty Internal Grinder is producing a finer finish because of the lubrication obtained by the use of cutting oil instead of water-soluble coolant. Tolerances are held to within. 0003" (Three ten-thousandths inch) with controlled oil temperature.

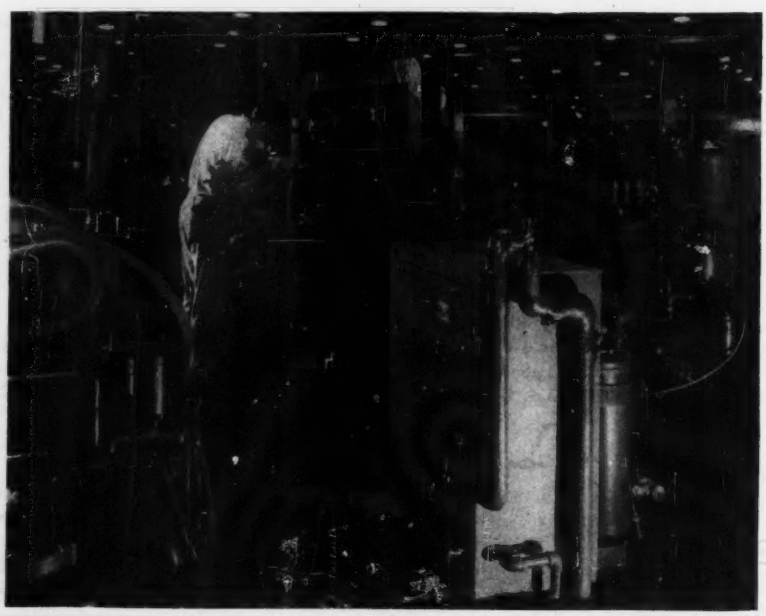


The Bryant Heavy Duty Internal Grinder in Operation. At the right of the picture is the "Packaged" Liquid Cooler which cools the Cutting Oil for this Machine.

To:
Jones and Lamson Automatic Thread Grinder

This machine tool was used to grind threads from solid stock. Before a liquid cooler was installed, there was a frequent burning of the workpiece because of the extremely high temperature of the cutting oil.

After the cooler was installed the oil temperature was maintained at a uniform 70° F; workpieces were more uniform; all signs of burning were eliminated; the danger of the workpiece shrinking or growing was removed; tolerances were held easily; and an increase of 25 per cent in production was noted by speeding up the grinding wheel and eliminating delays caused by heating.



A Jones and Lamson Automatic Thread Grinder, with the Mechanically Refrigerated Liquid Cooler for Cooling Cutting Oil in the Left Foreground.

**Case histories and photographs courtesy of Airtemp Division, Chrysler Corporation, Dayton, Ohio.*

Improvement in Service Performance of Lubes and Greases

By C. M. LARSON — *Sinclair Refining Co.*

Aircraft Oil

Today the world's leading industry is aircraft. It is certain that as a postwar industry it cannot maintain that position but it can support 8% to 10% of the present volume which would be a growth of 1000% over 1938. The acceptance by the general public of civilian aircraft is one of your most future concerns as airline and military use of aircraft lubricating oils are national and international in scope, so out of your sphere of selling. The younger generation is taking to flying as we did to the automobile and they represent a great future potential market to the petroleum industry. Many executives are also planning planes for their companies' post-war. In 1940 there were actually about 25,000 light planes used in private flying. Eight to ten years after the war it is estimated that there should be about 300,000 to 400,000 small planes and a yearly production of 20,000 to 40,000 such planes shortly after the war.

For the first five years after the war the volume of aircraft lubricating oil will be small as compared to your motor oil sales, probably 3% to 5%, but if you are to develop this market the proof that you have an oil of aircraft quality is one of getting into this field from the very start.

Just how much policing outside agencies, such as the CAA, will play or whether only aircraft engine manufacturers' approvals will prevail, is a part yet to be determined. It is a known fact that 95 Viscosity Index Minimum still is a requirement and Pennsylvania Aircraft Oils for World War II are tops, such as was the case in the last World War I. Even though the temperatures of the cylinders are higher, the horsepower per cubic inch is greater and the octane numbers are greater than 100, mineral oils are used in preference to additive type aircraft oils of equivalent SAE number and VI. Oxidation resistance to lacquer, corrosion and viscosity build up, as well as sludge and low engine wear, are of utmost importance.

Gear Lubricants

Even more impressive perhaps than other lubricants is that of the All-Purpose Noncorrosive Gear Lubricant. Originally designed to fill Army requirements for minimum inventories and ease of application, this product is beng developed to meet dealer and commercial requirements. Such products require a very stable mineral oil to which are added certain film strength additives which will handle the high rubbing gear tooth speeds of the passenger car, and yet give low tooth wear in high torque truck and tractor service.

Such all-purpose gear lubricants must have oxidation resistance of straight mineral or motor oils and absence from corrosion during usage and with all kinds of metals met with in the transmissions or rear axles of our present and future cars and trucks. These lubricants have definite character, based on service performance yardsticks rather than physical tests or specifications, as written in the past.

Chassis and wheel bearing greases are undergoing even greater changes of manufature than lubricating oils. The war has put new emphasis on the development of all types of greases. It has forced research in grease development in the past two years to more advances than in all the last ten years. Just now with powder dry soaps and continuous methods of heating and cooling apparatus available, our existing kettle methods in making grease, whether soda, aluminum or mixed base, will be obsolete in another five years. Of course, future design of wheel bearings, chassis fittings and bearings will advance. Some predict the self-sealed bearings, such as used in aircraft, but this should not upset your dealers as they will be giving a wider range of service to the motoring and flying public than chassis, gear and motor oil lubrication.

Hydraulic Fluids and Lubricants

The aircraft industry's development of hydraulic lubricants and fluids, coupled with the recoil requirements of Army and Navy Ordnance, not to mention the fluid drive of our splendid tanks, have given the automotive engineer and the petroleum industry a new concept as to what constitutes a hydraulic oil. The postwar car, truck, and bus will tend toward fluid drive which requires oils of low temperature-viscosity change and with fairly high resistance to oxidation. Whether the Heavy Duty 10W Motor Oils, such as now used, or whether subzero hydraulic oils, such as called for by aircraft control mechanism, is a matter of postwar design revealed when the automotive industry exposes its hand during 1946 and the following years.

New Rust Preventives

Never before has the problem of rust and rust losses, which were accepted as a nuisance, resulted through the war in developing petroleum products to eliminate and safeguard equipment. The necessity of treating mechanical equipment against rusting is, of course, obvious. The types vary widely and they are designed to meet specific conditions of operation, storage and shipment. Farmers are using the general purpose rust preventive oil, whereas truck and tank manufacturers are filling the crankcase of new equipment awaiting storage or shipment with the crankcase or motor oil, SAE 10 and 30 grades of rust preventive lubricating oil. These grades are also suitable for winter storage of marine engines.

As a postwar contribution these rust preventive lubricating oils, greases and waxes will preserve the hundreds of millions of dollars of automotive, ordnance and marine production equipment, as well as the vehicles and motive power made obsolete by the ending of World War II. These rust preventive products will also be part of our civilian conservation program of the future.

You can see by the foregoing that the horizon is bright for those that are prepared to meet these new changed conditions.

Mr. C. M. Larson, a Member of the A. S. L. E., recently prepared an article on Lubes and Greases for the "National Petroleum News Oil Marketer's Convention in Print". We are printing a portion of this article to give our readers some of the significant changes and developments which, he indicates, have taken place.

Mr. Larson is Chief Consulting Engineer of the Sinclair Refining Company and Chairman of its Products Committee. He is past Vice-President of the Fuels and Lubricants Activity of the S. A. E., and Chairman of Committee D-2s of the American Society for Testing Materials.

News releases describing new products or new equipment in the field of lubrication and its application will be welcomed by the editor, as will pictures, charts, line drawings, etc. Please address communications to:

Mr. B. H. Jennings, Editor,
Lubrication Engineering
Northwestern Technological Institute,
Evanston, Ill.

Carbide Offers New Lubricant

A new internal combustion engine lubricant having unusual advantages over mineral oil, particularly for cold weather use, has been announced by Carbide and Carbon Chemicals Corporation, a Unit of Union Carbide and Carbon Corporation. This lubricant, which is now being produced in commercial quantities, has properties quite different in many respects from oil derived from petroleum.

The lubricant can be manufactured to any desired viscosity and is claimed to be wax-free. Pour-points vary from —30 F to —80 F. Flash-points range from 300 F up. The new materials have densities approximating that of water. The manufacturer states that carbon residue values are less than 0.01 per cent, regardless of viscosity. The lubricant is characterized by low change of viscosity with change in temperature, having viscosity indices in the range of 140 to 160.

Carbide's new lubricant contains no petroleum oils. Its use in internal combustion engines has been studied for several years in a large number of vehicles which have covered a total of over one and one-half million road miles. Large quantities are being used in military equipment.

Carbide claims that these new lubricants practically eliminate sludge and varnish formation in the engine and that wear of the moving parts is in line with wear experienced with ordinary mineral oils. East of starting in cold weather is an outstanding advantage.

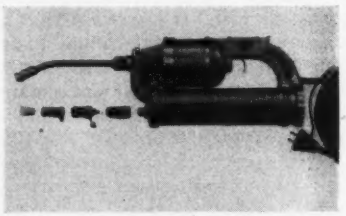
It is claimed that there are indications already that these lubricants will be widely used in internal combustion engines when they are available for other than critical military use.

These compounds are manufactured in two types, water soluble and water insoluble. The latter type is used for lubricating internal combustion engines. Other applications may include lubrication of refrigerating machines and all kinds of machinery operated under conditions of low temperature or where a non-sludging oil is required, and as hydraulic fluids, textile lubricants, plasticizers, in leather treating compounds, wire drawing lubricants and heat transfer liquids. Greases having unusual high- and low-temperature properties have been prepared from these lubricants.

At the present time, the sale of these lubricants is restricted to war uses.

Electro-Draulic Grease Gun

The John W. Hobbs Corporation of Springfield, Illinois, announces a new improved all electric grease gun identified by the trade name "Electro-Draulic."



The gun weighs but 7 pounds and is equipped with a 10000 rpm motor. A cam at the end of the motor shaft actuates four pistons forcing the lubricant into the compression chamber, developing pressure in excess of 10000 pounds per square inch.

The pistol grip and the trigger switch assure ease of handling and absolute control as the discharge stops or starts instantly.

The grease magazine holds one pound of grease and it is claimed a saving of from 25% to 50% of lubricant is effected because the operator has absolute control as to the exact amount of grease expended.

The Electro-Draulic Grease Gun is shipped completely assembled with 20 feet of heavy-duty cord with four adapters which fit all types of car fittings. It has also been used in industrial plants where the importance of proper lubrication is appreciated.

Full descriptive matter may be had by addressing John W. Hobbs Corporation, Electric-Draulic Division, 3040 Yale Blvd., Springfield, Illinois.

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The Four-Ball Machine

(Continued from page 43)

creased slowly until upon reaching about 250 ohms violent oscillations of the ohm meter occurred for a moment, after which the resistance suddenly fell to very low values. This critical velocity occurred at almost the same speed that was obtained graphically from the friction-vs.-speed curves as shown by the data in Table II.

TABLE II

Comparison of Critical Velocities Determined by the Electrical and Graphical Methods for Various Lubricants

Lubricant	Critical Velocity, R.P.S. Graphical	Electrical
White Oil	—	2.25
Penn Bright Stock	0.28	0.30
White Oil + 1% Penn B.S.	0.36	0.53
Motor Oil, SAE 20	0.35	0.60
Castor Oil	0.50	0.83
Penn Neutral	—	0.90

The Four-Ball Wear Top was used for measuring wear in two ways. The first was to run a test for 2 hours at 14.4 kg load and determine the diameter of the wear spot and quantity of iron abraded. The second was to determine the time required to wear through a thin plating placed on the top rotating ball. When this was a metal such as copper or gold, it was possible to determine within rather accurate limits the time to wear through the plating by periodically removing the upper ball and chuck and determining whether etching (of steel) occurred with dilute acid. It was thus possible to study the antiwear action of a large number of additives which led to the development of the eutectic theory of wear prevention.[7]

General Remarks

In the above discussion of the various four-ball machines no detailed experimental techniques are given. However, in experiments of the type described it is essential that great care be taken in cleaning the balls and the ball holders. The procedure recommended by Beeck (ref. 7, page 94) is followed, which involves removal of the oil followed by heating with alcoholic potassium hydroxide, and final washing. Use of the best steel balls obtainable (such as Grade 1 SKF preferably of a common lot number to insure uniform hardness) is desirable, particularly for experiments under non-seizing conditions.

Although in this review the use of the four-ball machines in research on lubrication processes and evaluation of oils on a laboratory basis has been emphasized, it should be recognized that occurrences at the rubbing surfaces of operating machines and in the four-ball bearing may be identical. The simplification provided by the laboratory machine makes it possible to separate and study the various factors involved. Thus, once the conditions of operation of the four-ball apparatus which correspond to a given application have been established, it provides a very useful means for studying not only the lubricant but other factors as well.

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Engine Preservative Oils

(Continued from page 48)

lubricant by constructing it from various materials each of which fulfills a requirement by itself. This is a much more efficient way than looking for a single material which will solve all the problems, disregarding at the same time all theoretical conceptions.

In the first case the chemist can assume in advance which materials are likely to work out in solving his special problem. The universal solution may mean aimless stabbings in the dark with a great waste of time and no assurance of success.

In the big raw material shortage of the present day we cannot afford to solve problems by this "universal" method. The chemist has to get well acquainted with the available raw materials and with the physical-chemical action they will exert.

If basic rules which have to be followed are discovered, nobody will have to depend upon any single material or combination for getting a high-quality engine preservative oil. These rules, however, can only be developed by laborious experimentation.

In considering the possibilities of how to find the best inhibitors for each of the requirements that have to be fulfilled, we agree with V. A. Kalichevsky, who says: "The field

(Continued on page 60)

APPENDIX ONE

Typical inspection data from successful L-4 test on an AXS-934 oil

Sample Number	Hours	Neutralization Number	Naphtha-Insoluble Matter per cent	Naphtha-Insoluble Matter Soluble in Chloroform Method A per cent	Conradson Carbon Residue per cent	Ash	Viscosity Saybolt Universal @ 100 F., sec.
1	0	0.46	0.97	0.38	1.08	0.85	500
2	8	1.45	1.01	0.53	1.62	1.12	552
3	16	1.97	1.38	0.89	2.16	1.27	602
4	24	2.34	2.67	1.07	2.00	1.34	630
5	36	2.62	2.87	0.96	2.52	1.48	695

(Continued from page 59)

is still open to new discoveries. Empirical methods of locating new inhibitors cannot yet be entirely abandoned in favor of purely theoretical deductions."[16]

Summary:

The use of rust inhibitors in engine lubricants is very recent. In the development of this problem three phases are distinguishable:

Phase one: the oil is a preservative exclusively for engine storage.

Phase two: present usage when the engine preservative oil is also a lubricant.

Phase three: will be the future when all lubricants will have preservative qualities. Government specifications AXS-674 and AXS-934 are discussed in detail concerning requirements and outlines for possible solution are given.

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[15]R. S. Wetmiller & Bruce Hegeman: *S.A.E. Journal,* Dec. 1943.

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Acknowledgement

The author wishes to thank Mr. G. A. Daubert, President of the Nox-Rust Corporation, for permission to publish the data presented in this paper. Acknowledgement to Mr. N. C. Penfold is gratefully made for his careful review of the paper and his aid in assembling the engine test data.

Limitations of Greases for Bearing Lubrication

(Continued from page 49)

6. Viscosity of Oil

The viscosity of the oil used in making the grease may play an important part. The average ball bearing grease today contains an oil of about 300 seconds at 100 F, while a few go up to 500 seconds at 100 F. Some of the high-temperature, high-speed greases contain still heavier oils. In general, an oil that is too heavy in a grease causes the bearing to run warmer, which is usually undesirable. If the oil viscosity is very light, as in the case of low temperature greases, where it may average only 60 seconds at 100 F, the grease will not stand very heavy loads.

7. Soap

The nature of the soap in a grease may also have an effect on the temperature limits. A straight stearate will stand slightly higher temperatures than a mixture of oleates, palmitates, etc., and more complex soaps may have still more pronounced effects. The purity of the stearates used in low-temperature greases may also affect their low-temperature properties.

8. Effect of Metals In Bearings

If bearings contain bronze retainers, the stability of the grease is a factor to be considered, especially if the temperatures should rise above 175 F. All of the lithium soap greases have not been checked, but at least one or two will stiffen decidedly under heat in the presence of bronze.

9. E. P. Additives

We have had no experience with grease containing E. P. additives, but we do believe that such greases have a definite place, especially in the steel industry.

10. Age Hardening

If the grease is of a type that hardens in service and does not bleed a small amount of oil at intervals from the hardened soap structure, the bearing will fail from lack of lubrication. But it is possible to have a grease that apparently is channeling very badly, yet sufficient oil is being released to provide lubrication and prevent bearing failure.

11. Sealed Bearings

Double-shielded or sealed-for-life bearings are used as supplied by the bearing manufacturers. The grease in these may vary with the bearing manufacturer, and, in general, these greases are quite stiff in consistency. This type of bearing is used for fractional-horsepower motors and is apparently quite satisfactory.

Most of the troubles that develop with greases come from over-greasing the bearings, with a subsequent rise in temperature and breakdown of the grease. With all their limitations, greases have some advantages over oils, such as stability to operate over a wider range of temperatures, less frequent attention and application, ability to keep dirt out and to enable apparatus to be operated in a vertical position without leakage of lubricant. There is less danger of rusting due to the draining of oil from the bearing surfaces when not in use for long periods of time. The use of grease for ball and roller bearings in our field seems to be expanding.

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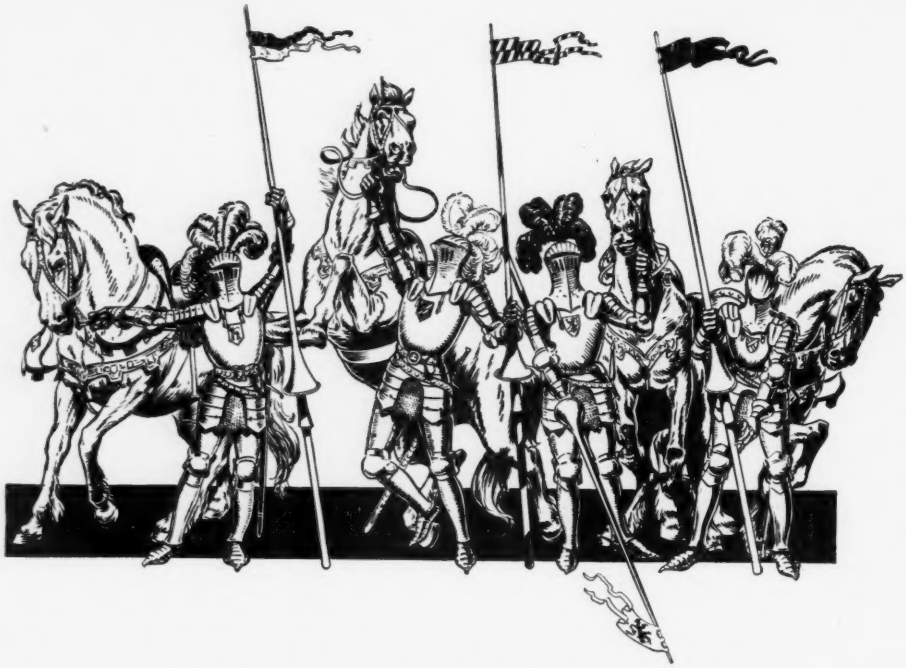

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For building into the wire strands, fibre centers and final laying up of finished cable.

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For treating the fibre in process of manufacture and building into the yarn, into and between strands, and between the center and surrounding wire strands. Will not squeeze out and unusually water-resistant.

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